A STUDY ON LOW-CARBON SOCIETY DEVELOPMENT IN BANGLADESH(Dissertation_全文)

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LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

According to the Next Eleven of Goldman Sachs and D-8 economies, Bangladesh is having a high potential of becoming prospective economy for investment and future growth in the 21st century. Bangladesh is historically agrarian country, the share of agricultural sector in national GDP has shrunk from over 30% in 1980 to below 20% in 2011. On the other hand, industry is growing from lower than 20% in 1980 to over 30% share in GDP (2011). The economic structure is rapidly developing as market based economy. The economic growth rate had been 6-7% per year for the past three years and the country has the national target to be a middle income country (MIC) with 2,000US$ per capita income by 2021. The government of Bangladesh has the national target to achieve of providing 100% of electricity access to people by 2021 and has planned to generate coal-oriented power plant of capacity 2900MW in the next 5 years to utilize significant reserves of high quality coal in the country. Ministry of planning (2010), projects probable energy mix for electricity generation which consists of coal 53% in 2021 (4% in 2010). Such projections on power generation indicate an increase in fossil-fuel (especially coal) dependent energy consumption and Bangladesh's carbon intensity as well. With lesser agriculture and more industry, more emission will be given off to the atmosphere. Also, over exploitation of forest plants will hinder chances of carbon sequestration.

Bangladesh emitted 117 million tonnes of CO_2-eq ($MtCO_2$-eq) with emission from waste in 2005 (MoEF, 2012). The largest source of GHG emission is energy (85%) followed by agriculture. Land use change and forestry resulted in net removals of 6.5 $MtCO_2$-eq (-7%) according to the country's Second National Communication (MoEF, 2012). Based on the emission inventory, GHG emission was increased 2.4 times in 2005 from 1994 and agriculture and energy posed as potential sources of GHG emission in 2005. Per capita GHG emission was increased 2 times in 2005 from 1994 and in some coming decades, it might have robust possibility to reach or overlap the world's GHG emission per capita target 1.92tCO_2-eq of

2050.

Bangladesh emits small GHG; however is the most climate vulnerable country in the world due to unpredictable future of climate change. The country is facing enhanced severity of natural disaster because of global warming. The government thus recognizes that climate change is a development as well as an environmental priority and is committed to developing and incorporating potential response measures that reduce the impacts of climate change into the overall development planning process. Bangladesh is not obligatorily committed to reduce GHG emission but it has to achieve sustainable socio-economic development. In long term development pathway, if it does not have any intervention of abatement countermeasures, this country will contribute a significant GHG emission. The emission will impose direct impact on local environment and society and contribute a share in world's GHG emission in future. In order to prevent this danger, socio-economic development must run with low-carbon society's development. The process of moving to a low carbon development must take the factor into consideration and focus on the distribution of benefits to its population; socio-economic benefits comprise increases in farm income, social infrastructure development, recreation enhancement and health benefits. To combat climate change and at the same time attain economic sustainability, countries should implement measures that foster energy exploitation, processing, production and utilization in a low carbon way.

The government of Bangladesh thus recognizes that climate change mitigation is a development as well as an environmental priority and is committed to developing and incorporating potential response measures that reduce the impacts of climate change into the overall development planning process. Bangladesh is focusing primarily on climate-resilient growth through adaptation measures and also taking steps to pave mitigation and low carbon growth. However, there is an immense lack of concrete climate change policy that specifically aims the selection of suitable climate change reduction measures and integrates in the development policies of the country. Hence, Bangladesh needs some effective initiatives to promote reduction measures, assess the mitigation potential in major prioritized sectors (agriculture and energy) and develop low-carbon scenario to run development process sustainably for the country.

Therefore, the objective of this study is to give an initial vision of possible low-carbon society (LCS) scenario in Bangladesh, which consists of future changes in demography, transport, industry, energy demand, crop production, livestock number, landuse pattern, GHG emission and emission reduction. Extended Snapshot (ExSS) and Agriculture, Forestry and Other Landuse Bottom-up (AFOLUB) models are used to estimate GHG emission and mitigation potential in energy and AFOLU sectors of Bangladesh, respectively. ExSS estimates socio-economic activity level, energy demand, CO_2 emission and reduction potential through reduction measures. AFOLUB projects future GHG emission from AFOLU sectors and estimates mitigation potential under several constraints for mitigation costs. Moreover, AFOLUB model help to analyze the effect of policies such as emission tax and so on. This research finding is the comprehensive forecast of changes in GHG emission based on renewable energy development, power sector improvement in energy sector and maximization of profit in agricultural production and of mitigation potential in the land use sector. A package with reduction measures towards LCS development in Bangladesh is also proposed by 2025.

The main outcomes of these models estimation are as, under the scenario of 2025BaU (without applying reduction measures) GHG emission will be increased to 309.8 $MtCO_2$-eq which is about 3.5 times larger than base year of 2005 (87.9 $MtCO_2$-eq) and under the scenario of 2025CM (with selected feasible reduction measures) GHG emission will be reduced to 182.4 $MtCO_2$-eq which is 41% smaller than 2025BaU emission. Efficient lighting, improved cooking stove in energy sector, midseason drainage, replacement of roughage with concentrates and enhanced natural regeneration in AFOLU sectors are the most promising and proposed measures contributing 38% of total emission mitigation potential. Selections of reduction measures depend on country’s socio-economic condition and existing policies which can be explored at present time of rapid development.

The results of this study are very outstanding from the point of view that ExSS can assess the effect of consensus and synergy effect among the targets including low carbon target by giving future state which are achieved as socio-economic assumptions. The AFOLUB model can solve the profit maximization problem under several constraints for estimated demand of agricultural and woody products. Moreover, the AFOLUB model can help analyze effect of policies such as emission reduction incentives and so on.

This research work is the first attempt to utilize socio-economic models which create future energy scenarios of clarifying the growth in energy demand of respective energy sectors and forecast overall GHG emission in two scenarios for Bangladesh. The methodological approach of this study will provide necessary quantitative information of mitigation opportunities in raising efficiency in the production and consumption of energy, GHG emission and emission reduction in future. Moreover, this current research work serves essential socio-economic data and a package of reduction measures contributing reduction in GHG emission as well as energy demand for policy makers, administrators, stake-holders and academic researchers in integration of those actions in development policies to achieve sustainable development in Bangladesh.

Chapter 1 Introduction

1.1 Country background

Since Bangladesh achieved independence in 1971, GDP has grown nineteen times, GDP per capita has eight times, food production has increased three times and the population growth rate has declined from around 2.9% per annum in 1974 to 1.5% in 2011. Between 1991 and 2005, the percentage of people living in poverty has declined from 59% to 40%. This country is positioned as 9^{th} place as the most densely populated with 1,099 persons/sq^2 in the world. The population growth rate in Bangladesh has been declining significantly to 1.3% in 2009 from 2.1% in 2006 and then again increasing to 1.5% in 2011. However, the population growth shows inconstant rate, still population density increases to 964 persons/km^2 in 2011 from 834 persons/km^2 in 2001 (MoEF, 2012). GDP per capita in Bangladesh grows sharply 588US$ in 2012 from 399US$ in 2004 (CPD, 2012). However, GDP growth rate decreases to 6.3% in 2012 from 6.7% in 2011, due to unfavorable external economies and internal supply constraints (CPD, 2012). Per capita income has reached 848US$ in 2012 from 818 US$ in 2011. However, there is still way short of 1,152 US$ needed to meet the national target to be the middle-income country with 2,000 US$ per capita income by 2021 (Ministry of Planning, 2010). Walud et al. (2011) state that GDP and energy demand have intrinsic relation, as GDP drives the energy demand (Paul and Uddin, 2010) and GDP fluctuation cause electricity demand fluctuation in Bangladesh (Mazumder and Marathe, 2007). More than half of GDP is generated through the service sector; industry contributes 30% and agriculture makes up about 20% of GDP in 2010. Garment exports and remittances from Bangladeshis working overseas also fuel economic growth. Garment exports account for around 84% of total manufactured exports in 2011. Still Bangladesh is one of the most energy-starved countries in the world and annual per capita energy consumption is 0.2toe in 2005 which is much below than world's average of 14.7toe (2005) (Munim et al., 2010). EIA (2012) reports that energy intensity in Bangladesh increases to 0.33 (kgoe/US$GDP in 2005) in 2009 from 0.31 (kgoe/US$GDP in 2005) in 2005. Lower energy intensity indicates that higher GDP per unit energy use. Per capita electricity consumption in Bangladesh is 279 kWh (World Bank, 2013) and 47% of people can access to electricity in 2010 (Ministry of Planning, 2011). Electricity consumption per capita of Bangladesh is extremely low compare to neighboring countries in Asia in 2010 (Fig. 1.1) (World Bank, 2013).

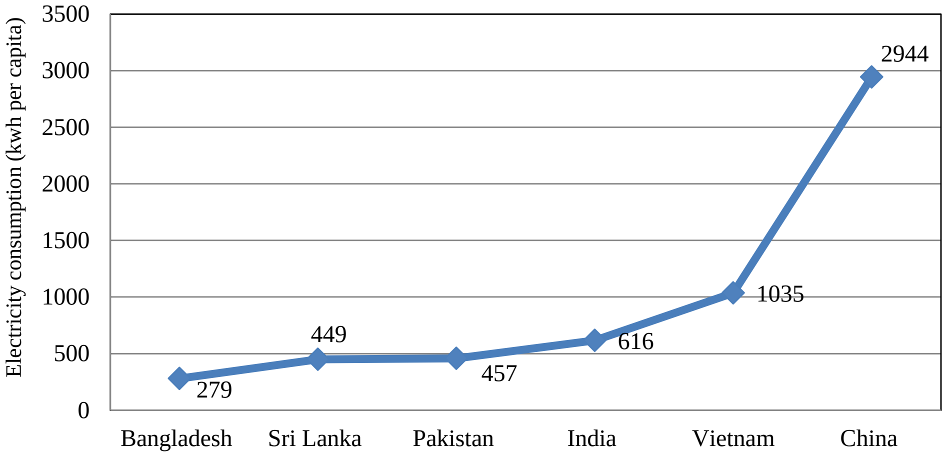


Fig. 1.1 Electricity consumption per capita

In rural areas, about 75% of people reside and the availability of electricity is for only 22% of rural people in 2003 (Bangladesh Bureau Statistics, 2003). The main energy sources in this country are biomass and natural gas. Biomass and natural gas comprise of 40% and 39% of primary energy supply in 2005 respectively (IEA, 2007). The rest share of primary energy is covered by commercial fossil fuel (e.g. oil) with small share of 1% of renewable (solar and wind) energy. Bangladesh has a significant reserve of natural gas (20.5 trillion cubic feet) which is the main fuel (88%) for electricity generation (Ministry of Power, Energy and Mineral Resources, 2004). Energy and power division of Bangladesh (2010) indicates that the existing gas reserves will be able to meet the gas demand up to 2016 with the present production capacity (Ministry of Power, Energy and Mineral Resources, 2010).

Ministry of planning (2010) reports natural gas reserves cannot meet the increasing demand of 5.6 billion cubic feet in 2025. As the gas reserves are fast depleting and Bangladesh is seeking alternative ways to produce electricity. To meet the rising demand, policy-makers are going for costly options such as diesel/furnace oil-based rental and quick rental plants for production of electricity. Also natural gas is being diverted from fertilizer industry to electricity production (which increases the need to import fertilizers). Bangladesh has significant reserves of high quality coal, and its exploitation is seen as an important option for Bangladesh to address its ‘energy security needs’ for the foreseeable future. The government projected that in 2030 the electricity generation capacity from various primary fuel sources would be: domestic and imported coal-based: 19,650 MW; gas and LNG: 8,850 MW; nuclear power: 4,000 MW and hydro and renewable: 2,700 MW (Energy and Power, 2011). Therefore, coal is expected to share as substantial fuel for electricity generation in future and to increase Bangladesh’s carbon intensity. Access to biomass is becoming more expensive and scarce due to high demand. The country’s reliable base of electricity generation capacity in 2008 is about 4,300 Megawatts (MW), with peak output on most days between 3,500 and 3,800 MW. But peak demand is estimated to exceed 5,000 MW, creating 30% of gap between demand and supply (World Bank, 2008b). Additionally, the infrastructure for electricity generation, distribution and supply with system loss of 6.4% are deficient to match the growing electricity demand of 10% of the country (Ministry of planning, 2010). Forestry is an important sector in Bangladesh’s economy. Bangladesh is green, though it is a forest poor country, having only 6.7% of the total land cover and shares 1.8% of national GDP. However, main fossil fuel reduction, over exploitation of biomass, less forest area, high dependency of imported transportation fuel, poor knowledge on future energy demand and supply are some of the imperative obstacles against sustainable development in Bangladesh. Therefore, availability of sufficient and consistent energy supply through proper energy planning is the prerequisite of further development for the country (Walud et al., 2011). Bangladesh, net forest land area is shrinking due to rapid population growth, urbanization rate and economic development to meet the increasing needs for cooking fuel. Natural forest areas constitute almost 31% and forest plantation 13% of forest areas in Bangladesh (Bangladesh Centre for Advanced Studies, 2000a). Despite Bangladesh's inadequate and poorly managed energy infrastructure and less forest land, the country is the most vulnerable country to climate change effects in the world with low per capita GHG emission 0.8 ton of CO_2 in 2005 (MoEF, 2012) (Fig. 1.2).

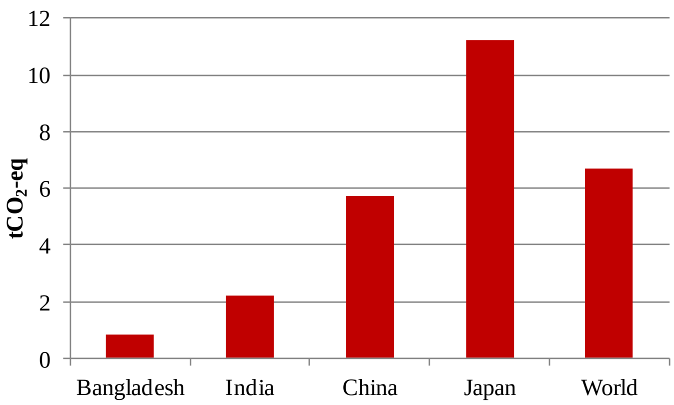


Fig. 1.2 Per capita emission in 2005

Bangladesh's share in CO_2 emission is mostly due to a growing population and economic growth both of which lead to an increase in energy consumption, despite the increasing use of alternative energy. Bangladesh has an agrarian economy; the whole agricultural production and cropping pattern are highly dependent on climatic condition. Moreover, Bangladesh with high population density and limited forest land is being highly sensitive to this climatic change. Being a low laying deltaic country, Bangladesh will face the serious consequences of sea level rise including permanent inundation of huge landmasses along the coast line. There is a clear evidence of changing climate in Bangladesh which is causing changes in the precipitation, increasing annual mean temperature and sea level rise. During a period from 1961 to 1990 the annual mean temperature increased at the rate of 0.0037 degree Celsius but during 1961 to 2000 the rate was 0.0072 degree Celsius. This mean, in the last decade, annual mean temperature rise was almost double than the previous. IPCC (2007) forecasted that mean temperature increases of 1.4°C and 2.4°C are projected by 2050 and 2100 respectively and 1 meter rise in sea-level will inundate 20% of its landmass and thus affect the coastal agriculture. IPCC (2007) also projected an increase by 5 – 88 cm sea-level by 2100. Global climate change model shows that crop productivity will reduce by 8% of rice and 32% of wheat production by 2050 from 1990 level (IPCC, 2007). Climate change poses significant risks for Bangladesh, yet the core elements of its vulnerability are primarily relative. Between 30-70% of the country is normally flooded each year. The huge sediment loads brought by three Himalayan rivers, coupled with a negligible flow gradient add to drainage congestion problems and exacerbate the extent of flooding. The societal exposure to such risks is further enhanced by Bangladesh's very high population and population density.

Bangladesh government has taken some initiatives to cope with adverse effects of changed situation. Ministry of Environment and Forest (MoEF, 2008) has prepared Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2008 and revised National Adaptation Plan of Actions (NAPA), 2009 for planning and designing adaption and mitigation activities. These climate change strategies prioritize adaptation and disaster risk reduction most and also low-carbon development and mitigation and technology transfer with the provision of adequate fund by creating market place for domestic emissions transactions.

1.2 Global picture on GHG emission

GHG emission has increased steadily since pre-industrial times by 70% between 1970 and 2004 (IPCC, 2007). The largest growth has been observed in the energy supply sector (an increase of 145%) followed by the transport sector and industry at 120% and 65% respectively within this period (IPCC, 2007). Many analyses of GHG emission trends and projections focus solely on CO_2, as CO_2 is the largest source of GHG, accounting for 76% of all such emission. According to the IPCC (2007), CO_2 concentration has become a major and the fastest-growing factor in climate change. GHG emission reached the highest point in 2010, making it "extremely challenging" to prevent global temperature rising to dangerous levels

(IEA, 2011). The IEA (2011) reported that 30.6 $GtCO_2$-eq was emitted in 2010, up 4% from 2008 level of 29.3 $GtCO_2$-eq. About three-quarters of the 2009-2010 emission rise came from developing countries, although they only accounted for 60% of global emissions last year. In terms of fuels in 2010, coal accounted 44% of total energy-related CO_2 emission, 36% from oil, and 20% from natural gas. According to the Energy Information Administration of the U.S. Department of Energy (EIA, 2007), global CO_2 emission has been projected to rise to 33.9 $GtCO_2$-eq in 2015, and 42.9 $GtCO_2$-eq in 2030, at an average growth rate of 1.8% per year. The next most important non-energy GHG directly emitted through anthropogenic processes, are CH_4 and N_2O. Agriculture, forestry and other land use (AFOLU) sectors are one of significant sources of non-energy GHG emission, contributing 31% of the global emission in 2004, 14% of emission derives from agriculture and the rest 17% from land use, landuse change and forestry (LULUCF) (IPCC, 2007). Fig. 1.3 shows the sectoral shares of GHG emission in the world.

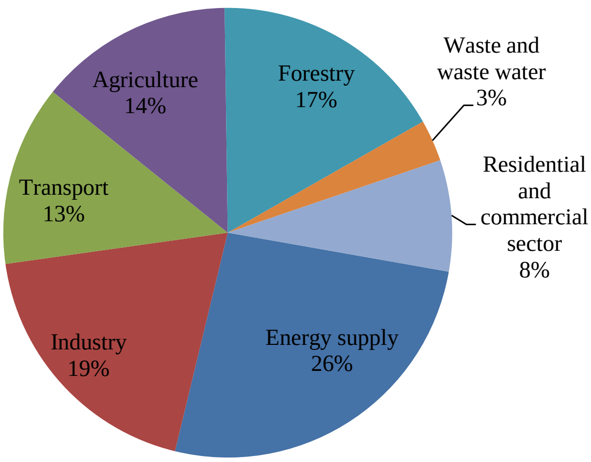


Fig.1.3 World GHG emissions by sectors

However, United Nations Framework Convention on Climate Change (UNFCCC) implies to achieve the stabilization of atmospheric GHG concentrations at a level that would prevent dangerous anthropogenic interference with climate system, allow ecosystems to adapt naturally, ensure food production not being threatened and enable economic development in a sustainable manner (IPCC, 2007). Meeting the objective of stabilizing greenhouse gas concentrations will, therefore, require fundamental changes in the way the world produces and uses energy, activities within AFOLU sectors as well as promotion of new and improved technologies could substantially reduce the economic burden of such changes (Clarke et al., 2008). In this context energy sector is the potential contributor in emission reduction. Efficient technologies for both energy use and supply and low- or no-carbon energy account for more than half of this mitigation potential (IPCC, 2007). FAO (2010a) estimated mitigation potentials of 5.5 – 6.0 $GtCO_2$-eq/year and 5.4 $GtCO_2$-eq/year in agriculture and forestry sectors by 2030 respectively.

Industrialized countries are obligated to reduce their emission and provide finance and technology to assist reduction of emission in developing countries. Developing countries insist that a solution to climate change cannot come at the expense of their development. Reductions of GHG emission in developing nations, primarily in the southern hemisphere, are also necessary, but economic growth and poverty alleviation are inexorably linked to lack of access to energy services and consequently, a seemingly inevitable increase in fossil fuel use and thus carbon emission.

1.3 National picture on GHG emission

Global climate change has become a significant international concern over the past decades and many climate change studies have suggested that Bangladesh would be victimized more with growing severity of global warming and associated rise of sea-level. In response to environmental concerns, Bangladesh became a signatory to the UNFCCC on environment and development in Rio de Janeiro, 1992. The government along with scientific community in Bangladesh is committed to analyzing the causes and implications of climate change and to developing an adequate response strategy to combat its possible adverse impacts. In 1994, to respond to the request by Ministry of Environment and Forest (MoEF), Bangladesh to the US government, Bangladesh government launched a country study. The study has provided a framework for carrying out the country specific greenhouse gas (GHG) inventory. According to the UNFCCC, like least developed countries (LDC), Bangladesh is not obligated to mitigate. Look upon the severity of the problems that climate change poses, the Conference of Parties (COP) call upon the developing countries to prepare and implement the Nationally Appropriate Mitigation Actions (NAMA) on a voluntary basis for mitigating climate change. In this course, the government of Bangladesh (GOB) prepared emission inventory for 1994 and 2005 named as Initial National Communication and Second National Communication (SNC) respectively and submitted to UNFCCC (MoEF, 2000 and 2010). Bangladesh's second national communication includes ideas, policies and actions for GHG emission mitigation. The anthropogenic GHG emission in Bangladesh has been increasing dramatically by 58% or 2.4 times between 1994 and 2005 and agriculture and energy posed as potential sources of GHG emission in 2005 (MoEF, 2012). Per capita GHG emission was increased 2 times in 2005 from 1994 and in some coming decades, it might have robust possibility to reach or overlap the world's GHG emission per capita target 1.92tCO_2-eq of 2050. Table 1.1 shows the GHG emission inventory of 1994 and 2005 in Bangladesh (MoEF, 2012).

Table 1.1 GHG emission inventory in Bangladesh (MtCO_2-eq)

Source	GHG emission (MtCO_2-eq)			
Source	1994	Share	2005	Share
Energy (Fuel combustion)	15	31%	38	32%
Industrial process (mineral products and others)	1	3%	3	2%
Agriculture	24	48%	43	37%
Land-use change and forestry	8	16%	18	16%
Waste	1	3%	15	13%
Total	49	100%	117	100%

MoEF (2010) also projected that the GHG emission from energy use will be increased by about 61% in 2025 from 2005. GHG emission is projected based on the expected volume of industrial activity and macroeconomic development scenario. According to MoEF

(2012) final energy demand in 2005 is 12707ktoe and will be increased to 31050ktoe or 62% in 2025 from 2005. It indicates that more energy demand (mainly industry 2.7 times and transport 2.0 times) are the major sources of CO_2 emission in 2025 from 2005 level. The other source of GHG emission (CH_4 and N_2O) resulting from rice and livestock farming, artificial fertilizer use deforestation and landuse change in AFOLU sectors in this country. Bangladesh has significant amount of 58% GHG emission from the agriculture (44%), forestry and other landuse sectors (14%) in 2005 according to the GHG emission inventory, is reported by SNC (MoEF, 2012). Bangladesh's contribution to GHG emission is minute.

In 2005, GHG emission from Annex 1 parties and non-Annex 1 parties 16.7 billion tonnes of CO_2-eq and 11.7 billion tonnes of CO_2-eq including LULUCF respectively. In contrast, Bangladesh emitted 0.117 billion tonnes of CO_2-eq (including emission from LULUCF and waste) in 2005 (MoEF, 2008). MoEF (2008) stated that Bangladesh is low energy consuming country with 89 kgoe per capita in 2004-05. Despite the low energy consumption, the country has to meet the current energy demand which is likely to grow 50% faster than GDP per capita in coming years. This figure indicates the significance of energy security in Bangladesh by developing efficient energy system which is not heavily reliant on excess emission. LCS scenario has strong potential to raise efficiency in production and consumption of energy, renewable energy development and lowers the GHG emission through applying reduction measures in energy sector (MoEF, 2008). In agriculture sector raising irrigation and water use efficiency (improved drainage in dried rice fields) through improved agronomic measures and proper water management can also lower the CH_4 emission from this sector (MoEF, 2008).

1.4 Importance of LCS for Bangladesh

LCS in a developing country is a combined concept that can develop a sustainable model which can meet economic development, life style improvements and climate change effects mitigation through using renewable energy, low-carbon energy mix, reduction measures in agriculture and landuse sector, utilizing funding, technology transfer and finally capacity building which contributes to the sustainable development of the total society. In that society, equal attention will be paid on environmental protection as well as other socio-economic security. For Bangladesh, the concept of LCS in energy sector serves the potential of CO_2 emission reduction and focuses on low-carbon energy mix and better energy efficiency which can meet the challenge of CO_2 emission reduction. For AFOLU sectors, LCS is to quantify future emission mitigation potential by using feasible mitigation technologies for developing sustainable agricultural and landuse practices. GHG emission reduction options include energy efficiency improvement in the demand and supply sides as well as renewable energy potential in the power sector and mitigation potential in agriculture and LULUCF sectors. Mitigation is not mandatory for Bangladesh; however, current rapid economic development enforces GDP growth rate to be accelerated. Therefore, the requirement of energy service and food will substantially increase with the growth of energy-intensive industry, sectoral energy service demand and agricultural product demand in the coming years and will emit more GHG in future. Reduction measures should be identified and implemented to reduce the current emission intensity, which can be increased in some decades and encourage the country capable of higher emission reduction to achieve these levels earlier through the use of better technology or other sectoral measures in order to market their emission credits. For Bangladesh, building LCS will be both a challenge and an opportunity; they have some benefits as,

- Suppress GHG emission increase
- Energy development (better energy efficiency, low-carbon energy mix etc.)
- Promote power supply with efficient energy management which enhances economic growth

1.5 Objectives of the study

Considering the importance of developing LCS and proposing a list of suitable reduction measures for GHG emission reduction in Bangladesh, the objectives of this study are as follows:

- Evaluate the future changes in socio-economic activity in energy sectors.
- Estimate the future changes in agriculture, livestock and land use in AFOLU sectors.
- Assess the future changes in energy demand in energy sector and GHG emission in energy and AFOLU sectors respectively.
- Recommend efficient measures to reduce future GHG emission.
- Quantify the reductions in GHG emission in CM (countermeasure) case from BaU (business as usual) case.
- Propose a package of reduction measures towards LCS development in Bangladesh.

1.6 Scope of the study

The scopes of this research work are as follows:

- Evaluate socio-economic changes and GHG (CO_2, CH_4 and N_2O) emission from energy and non-energy sectors (agriculture, forestry and land use change).
- Address suitable and cost-effective reduction measures which limit future emission as well as energy demand.
- Assess emission reduction, energy-efficiency improvements in several sectors (sustainable transport, industry, residential, commercial and power) and cost-effective mitigation potential in agriculture and LULUCF sectors.
- Create two scenarios, Business-as-usual (without applying reduction measures) and Countermeasures (with applying reduction measures), considering base year 2005 and target year 2025.

1.7 Overview of the thesis

This thesis is structured as follows (Fig. 1.3):

Chapter 1 provides background information about the present socio-economic, energy, agricultural and land use changes situation in Bangladesh, discusses the global and national characteristics of GHG emission and explains the objectives based on the background study.

Chapter 2 focuses on reviewing the current climate change actions and highlighting the major development national policies and aiming to explore the level of integration of socio-economic development, energy status improvement and promotion of sustainable agriculture practices in the national development policies.

Chapter 3 highlights detailed modeling framework of Extended Snapshot model (ExSS) which estimates socio-economic activity level, energy demand and CO_2 emission and reduction potential by reduction measures. Agriculture, Forestry and Other Landuse Bottom-up (AFOLUB) model, which estimates future GHG emission and mitigation potential in AFOLU sectors by using feasible mitigation technologies under several constrain of mitigation costs.

Chapter 4 consists of data collection and parameter estimation of socio-economic indicators and AFOLU sectors which are the input in the models and also the database source for the future LCS scenario development.

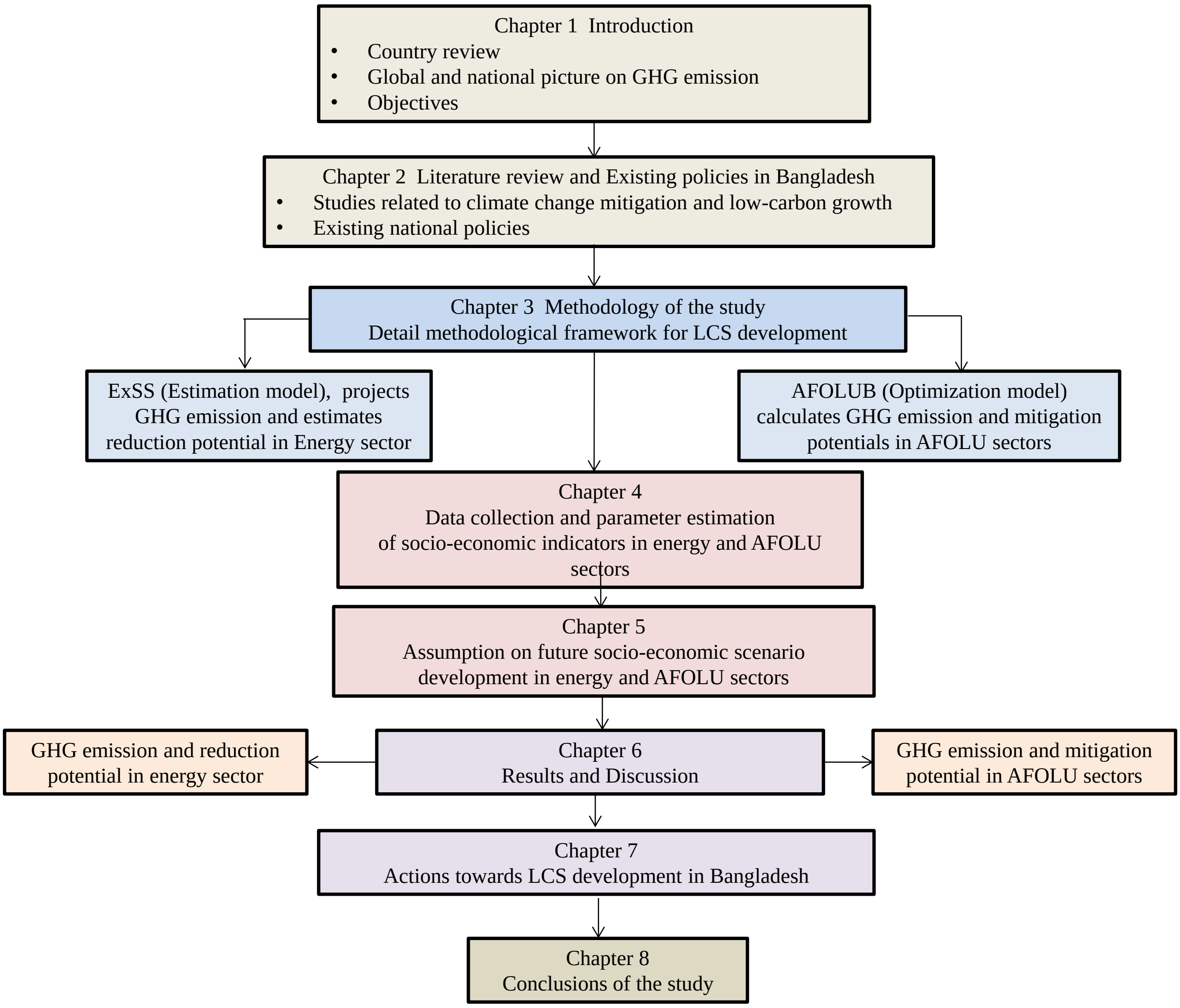
Chapter 5 provides assumptions behind the future scenario development and future changes in socio-economic indicators, crop production, livestock number and landuse pattern in energy and AFOLU sectors.

Chapter 6 describes the output the research work. This section explains the projection on GHG emission and estimation of mitigation potential in energy and AFOLU sectors in Bangladesh. The models are used to estimate the levels of GHG (CO_2, CH_4 and N_2O)

emission and mitigation potential under two scenarios of business as usual (BaU) and countermeasures (CM).

Chapter 7 analyses the results of modeling from above chapter in order to develop a package of required measures that would be feasible towards LCS development in Bangladesh. A comprehensive analysis of GHG emission and reduction and also energy savings through proposed mitigation technologies in all sectors are investigated in the chapter.

Chapter 8 represents conclusions of current research work.



ExSS: Extended Snapshot Tool

AFOLUB: Agriculture, Forestry and Other Land Use Bottom up model

AFOLU: Agriculture, Forestry and Other Land Use

Fig. 1.2 Structural framework of the thesis

Chapter 2 Literature review and Existing policies in Bangladesh

United Nations Framework Convention on Climate Change (UNFCCC) implies to achieve the stabilization of atmospheric GHG concentrations at a level that would prevent dangerous anthropogenic interference with climate system, allow ecosystems to adapt naturally, ensure food production not being threatened and enable economic development in a sustainable manner (IPCC, 2007). Bangladesh is critically vulnerable to climate induced hazards. The country has low level of GHG emission and its climate change strategies are hidden within government's long-term vision to eradicate poverty and to achieve national economic and social well-being. The key target is to halve poverty by 2015 in Poverty Reduction Strategy Paper (PRSP), finalized in 2005. Considering the threats of climate change poses to poverty alleviation, adaptation is being prioritized for the country. Low-carbon growth has not been included in policy priority yet, as Bangladesh has low level of industries and is struggling to extend energy services to much of its population. However, the government announced the targets of providing 100% electricity access to the people and becoming middle-income country with 2,000US$ per capita income by 2021 (Ministry of Planning, 2010). Therefore, Bangladesh's policy-makers have been compelled to meet the growing demand for electricity and economic growth through a number of initiatives within this time frame. The government projected that in 2030 the electricity generation capacity from various primary fuel sources would be: domestic and imported coal-based: 19,650 MW; gas and LNG: 8,850 MW; nuclear power: 4,000 MW and hydro and renewable: 2,700 MW (Energy and Power, 2011). These targets indicate the increase in energy demand and consumption and carbon intensity without implementing energy efficient and reduction measures. According to the Second National Communication (SNC) (MoEF, 2012), CO_2 emission in estimated of 36 $MtCO_2$-eq in 2005 in which industry sector and power generation accounted 36% and 35% of emission respectively.

In Bangladesh, AFOLU sectors contribute 57% (26% of CH_4, 18% of N_2O and 13% of CO_2) of total domestic emission in 2005 (MoEF, 2012). Enteric fermentation, manure management of livestock and rice cultivation emit 30%, 32% and 38% respectively of total 25.4 $MtCO_2$-eq of CH_4 emission in 2005 (MoEF, 2012). 16% and 18% of N_2O emissions come from nitrogen (N) fertilizer and livestock management respectively in 2005 (MoEF, 2012). The growing use of N fertilizers is also a concern. Application of N fertilizer also contributes more 30% increase of N_2O emission in 2000 than at the 1990 level. Crop biomass fertilizer and N fertilizer increased 33% and 63% respectively by 2000 from 1990s applied level. Gradual increment of N fertilizer starts from the 1970 by introducing high yield cereals (Institute for Energy and Environment, 2004). Additionally, ALGAS (Asia Least-cost Greenhouse gas Abatement Strategy) projects that GHG emission from agriculture will increase by 11% by 2020 from the 1990 emission level in the country (Bangladesh Centre for Advanced Studies, 2000a). In 2005, forest and land use sector contributes 31% of CO_2 emission in the country (MoEF, 2012). ALGAS projects that the emission will be increased to 10% by 2013 from 1990 level in the country (Bangladesh Centre for Advanced Studies, 2000a). Although, AFOLU sectors are expected to have great potentials in GHG emission reduction, mitigation technologies for AFOLU sectors of Bangladesh are not being described explicitly so far. Nationally, still no significant mitigation approach has been taken into account for GHG emission reduction in the country. Estimation of mitigation potential from AFOLU sectors and selection of appropriate measures in mitigation may play important role for GHG emission reduction for the country.

Therefore, this study investigates the future GHG emission and mitigation potentials through energy, agriculture and forestry activities. In brief, main perspective of this study is to develop the future scenarios of GHG emission and mitigation potentials through cost-effective reduction measures for energy and AFOLU sectors in Bangladesh.

Moreover, the objective of this review is to access strong points and limitations of the current related research in order to develop a comprehensive modeling framework for analyzing the low carbon development for the whole country.

2.1. Climate change policy in Bangladesh

Bangladesh is one of the most vulnerable countries to climate change impacts in the world. Cyclones, storm surges, floods are now becoming so frequent and will be more severe in the upcoming years. Almost all sectors are likely to be affected by climate change. Therefore, it is now inevitable to prepare adaptation plan against climate change to save the people and economy of Bangladesh. The work pressure will be reduced if there is a concrete national climate change policy. However, there is no concrete national climate change policy in Bangladesh that specifically aims the climate change risks.

Bangladesh government pays attention on climate change vulnerability with a vision to eradicate poverty and achieve economic and social wellbeing, through a Pro-Poor Climate Resilient Strategy. This strategy focuses on the adaptation and disaster risk reduction and also low carbon development, mitigation and technology transfer to build the capacity and spirit to meet the climate change challenges in the next 20 to 25 years. This strategy is mainly based on the four building blocks of the Bali Action Plan:

1) Food security, 2) water security, 3) energy security, 4) livelihood security

UNFCCC has launched four adaptation funds for developing countries, include:

- Least Developed Countries Fund (LDCF) helps to prepare National Adaptation Plan of Actions (NAPA).
- Special Climate Change Fund (SCCF) sup-ports a number of climate change activities such as mitigation and technology transfer.
- GEF (Global Environment Facility) Trust Fund prioritizes adaptation.
- Adaptation Fund (AF) under Kyoto Protocol assists developing countries to carry out “concrete” adaptation plan.

GOB prepared the emission inventory and submitted to UNFCCC in 1994. The government has formulated the National Adaptation Plan of Actions (NAPA) and submitted to UNFCCC in 2005 to get Official Development Assistance (ODA) through LDCF. Implementation of NAPA is in process. Under the clean development mechanism (CDM), Bangladesh has established two authorities, National CDM Board and National CDM Committee and accepted four projects in waste and energy sectors in Bangladesh. The government has formulated Bangladesh Climate Change Strategy and Action Plan (BCCSAP), 2008 which has been revised in 2009.

BCCSAP 2009 has identified six priority themes (T):

- T1. Food security;
- T2. Social protection and health;
- T3. Comprehensive disaster management infrastructure;
- T4. Research and knowledge management;
- T5. Mitigation and low carbon development and
- T6. Capacity building and institutional strengthening

In BCCSAP theme T5 **Mitigation and low carbon development** has 7 programs (P) and Actions under the programs.

P1. Improved energy efficiency in production and consumption of energy

Actions (A) under P1

A1. Study the future energy needs of the country and find out the least cost energy supply path that satisfies future energy demand based on the desired growth path of the economy

A2. Raise energy efficiency in power production, transmission and distribution through appropriate investments

A3. Raise energy efficiency in agricultural and industrial processes through appropriate policies and investments

A4. Raise energy efficiency in domestic and commercial/service sectors through appropriate policies and investments

A5. Raise energy efficiency in transport sector through appropriate policies and investments

P2. Gas exploration and reservoir management

A1. Invest in gas exploration

A2. Invest in reservoir management

P3. Development of coal mines and coal fired power stations

A1. Review coal mining methods and undertake a feasibility study to assess the technical, economic, social and environmental feasibility of coal mining for power generation (including factors such as how to capture coal bed methane)

A2. If the feasibility study is positive, invest in coal mining and coal-fired power generation plants using clean coal technology

P4. Renewable energy development

A1. Investments to scale up solar power programmes

A2. Research and investment to harness wind energy, particularly in coastal area

A3. Feasibility studies for tidal and wave energy

A4. Study of the techno-economic, social and institutional constraints to adoption of improved biomass stoves and other technologies

P5. Lower emission from agricultural land

A1. Support to research and on-farm trials of new water management technology on crop (including rice) land

A2. Support to agricultural extension service to popularize new water management techniques for rice production

P6. Management of urban waste

A1. Design of urban waste dumps so that methane can be captured in all major urban areas

A2. Using CDM mechanism to set up small power plants by capturing the produced methane from waste dumps

P7. Afforestation and reforestation programme

A1. Provide support to existing and new coastal afforestation programmes taking into account the future rise in salinity levels due to sea level rise

A2. Develop an extensive wetland afforestation programme to protect settlements against wave erosion

A3. Study the scopes of carbon credits under REDD (Reducing Emission from Deforestation and Forest Degradation) and invest, if appropriate, in reforestation of degraded reserve forests

A4. Provide support to existing and new homestead and social forestry programmes and enhance carbon sequestration

A5. Research the suitability of various tree species for their carbon-locking properties for designing various forestry programmes keeping in mind other environmental and socio-economic functions of forestry.

Greenhouse gas (GHG) emission by developed and developing countries; is the key reason of global warming resulting climate change. Bangladesh is an energy starving country. The country will be on one of the fast growing power markets with its population and growing energy demand per person, its fast growing urbanization, and its socio-economic development. At present the potential demand of power is 5569 MW and the supply is below 4000 MW. The country is dependent on the imported petroleum that is big burden on the economy. The per capita emission is only 0.3 tonne per person still much below the world leading countries (19.8 tonne per person for USA). However, Bangladesh is one of the most vulnerable to climate change effect in the world. In this regard, renewable energy resources appear to be the one of the most efficient and effective solution for clean and sustainable energy development in Bangladesh. Biomass is the dominating source of energy in Bangladesh. Biomass energy is used in a very traditional way. Biomass conversion to energy in the form of liquid, gaseous and solid pellet or briquette could be a viable option to reduce the pressure on the conventional fossil fuel. The geographical location of Bangladesh has several advantages for extensive use of grid connected solar electricity and standalone solar PV system.

2.2. Policy targets for socio-economic development

Millennium Development Goals (MDG) (General Economic Division, Planning Commission, GOB, 2009) -Target (2015) (selected issues):

Goal 1: Eradicate Extreme Poverty and Hunger (below US$1 per day (PPP-values) -

Reduce poverty level from 39% (2009) to 29%.

Goal 2: Achieve Universal Primary Education. Net Enrolment Ratio in Primary Education is 100%.

Goal 3: Promote Gender Equality & Empower Women. Share of women in wage employment in the non-agricultural sector from 24.6% (2008) to 50%.

Goal 7: Ensure Environmental Sustainability. Proportion of land area covered by forest (tree cover) 19.2% (tree density 10%) to 20% with tree density 70%.

2.3. National Energy Policy and vision on power sector in Bangladesh

In 2004, The Government of Bangladesh has released a draft, entitled as National Energy Policy (NEP). The NEP refers to “The importance of energy in socio-economic development” (Ministry of Power, Energy & Mineral Resources, 2004).

Considering the past experience, the objectives and targets are pointed for energy sector as Sixth Five Year Plan (SFYP) 2011-2015 (Ministry of Planning, 2010) with Vision 2021, as follows:

- Enhance and upgrade exploration and development of existing, new gas fields and possible gas resources into proven reserves.
- Integrate reservoir management in both public and private gas companies to provide reservoir data collection and supply security.

- Institute administrative, financial and legal reform in Petrobangla and companies.
- Reduce system loss and improve use efficiency.
- Improve supply security of petroleum products.
- Encourage public-private partnership for Liquid Nitrogen Gas (LNG) import and marketing.
- Explore and distribute of indigenous oil and gas.
- Expand Liquid Petroleum Gas (LPG) use for domestic consumption to discourage piped gas.

The government's Power System Master Plan (2005) projects that 62% and 72% access to power will be achieved in FY-2012 and FY-2014 respectively (Ministry of Planning, 2010). The following objectives for the sector have been aimed:

- Ensuring energy security.
- Improving the security, reliability and quality of electricity supply.
- Making the power sector financially viable and facilitating economic growth.
- Increasing the sector's efficiency and introducing a new corporate culture in the power sector entities.
- Using natural gas, coal and oil as the primary fuels for electricity generation.
- Ensuring a reasonable and affordable price for electricity and private sector participation.

GOB has defined its vision and policy statement in February 2000, "Electricity for all by 2021" in phases with the direction of the Article 16 of "The Constitution of the People's Republic of Bangladesh", to eliminate the inequality between the urban and rural areas standard of living. Government's Vision towards 2021 for electricity

2.4. Renewable Energy Policy, 2008

Ministry of Power, Energy and Mineral Resources (2008) has published the National Renewable Energy Policy draft. The aims of renewable energy policy are to set policies aiming for developing renewable energy resources (solar, wind, hydro) to meet 5% of the total power demand by 2015 and 10% by 2020.

Couple the potential of renewable energy resources and distribution of renewable energy technologies in rural, peri-urban and urban areas.

- Encourage and facilitate both public and private sector investment in renewable energy projects.
- Develop sustainable energy supplies.
- Scale up contributions of renewable energy to electricity production and heat energy.
- Promote appropriate, efficient and environment friendly use of renewable energy.
- Create enabling environment and legal support to encourage the use of renewable energy.
- Promote development of local technology in the field of renewable energy.
- Promote clean energy for CDM.

2.5. National Agriculture Policy (NAP), 1999

Ministry of Agriculture (MoA) has formulated policy document in 1999 in order to provide proper guidelines for various development activities relating to crop sector, which is the largest sector of agriculture. NAP has an overall objective, 18 subsidiary objectives and 18 programme areas (Ministry of Agriculture, 2006). The overall objective of the national agriculture policy is to make the nation self-sufficient in food through increasing production of all crops including cereals and ensure a dependable food security system for all. Policy priority areas include crop production, fertilizer, irrigation, agricultural research, land use and so on. The MoA prepared the New Agricultural Extension Policy (NAEP) in 1996 in accordance with the agricultural policies and priorities set out in the fifteen-year perspective plan 1995-2010. The main goal of NAEP is to encourage the various partners and agencies within the national agricultural extension system to provide efficient and effective services which complement and reinforce each other in an effort to increase the efficiency and productivity of agriculture in Bangladesh. The government also implementing programmes under agricultural policies (1999) in Bangladesh have expanded the use of high yielding variety of rice seeds, fertilizers and shallow tube-wells for irrigation. Irrigation coverage increased dramatically from 22.5% in 1980-81 to 51.5% in 2000-01 (Kumar, 2008). The crop sector accounts for 12% of GDP and occupies over three-quarters of the cropped area. This development strategy results, rice production tripled from 11 million tonnes in 1972 with an annual growth rate of about 3% during 1990 to 32 million tonnes in 2009 and wheat exceeded production of 2 million. Maize production increased by 138% during the period 1995/96 to 1997/98 (Farouque, 2006). Bangladesh has some future targets on agriculture that are as follows:

1) Self-sufficiency in food: 2013

2) Ensuring food security: 2017(a+a+n) (a+a+n=Availability, accessibility and nutrition).

According to the National Commission of Agriculture report (unpublished), 7% of GDP growth needs of 3.1% increase in demand for food crops. Targets are to increase storage capacities by building additional sizes of 50,000 tonnes by 2015 and 1 million ton by 2021 to facilitate safe storage of rice.

2.6. National Livestock Policy, 2005

A National Livestock Policy (Ministry of Fisheries and Livestock, 2007) was drafted in 1992, but it was not officially approved. Recently, the Ministry of Fisheries and Livestock has prepared new National Livestock Policy in 2005. There are two distinct objectives- supply of adequate livestock and livestock products for human consumption and supply of animal power and animal wastes for crop production and product processing (Ministry of Agriculture, 2006). Significant growth in the livestock sector has been observed, in which main contributor is commercial poultry sector. The demand for livestock products will be increased through the growing population, restrained growth of per capita income and higher income elasticity. The demand for milk, eggs, and mutton are increased by 6%, 5.2%, and 5.6% respectively with the growth rate of 4.4%. Annual growth rate for sheep and goat will be about 2%. There is a huge gap of 2 and 1/2 times, higher than country's milk production level, estimated in 2002. Therefore the target is to bridging this huge gap by 2021.

2.7. National Forest Policy, 1994

Bangladesh government has promulgated the National Forest Policy in 1994 and approved the Forestry Sector Master plan from 1995 to 2015. Both the documents have emphasized the afforestation program in the country with 20% coverage and increase the protected areas by 10% of the reserve forest land targeted in the Master plan by 2015 through the coordinated efforts of Government Organization (GO), Non-Government Organizations (NGOs) and active participation of the people. One of the key objectives of the policy is to conserve soil and water resources and strengthening agriculture sector with the expansion of agro-forestry. The Forestry Master Plan integrates various programmes for enhancing the involvement of rural population in forest sector activities. Its objectives include preserving existing values, conserving plants and animal variety and ensuring maximum benefit to local people (Ministry of Agriculture, 2006). According to the Forest Act of 1927, 18% or 2.6 million hectares of forest land mass of the country is being managed by the Forest Department of Bangladesh. However, according to the Forest Department, recently this department controls 10.3% of land surface. In forestry sector, to sustain the ecological balance and to increase the employment opportunity from social and agro forestry expansion projects, increment about 2.84 million hectares of tree cover is of prime policy in this sector. The target is to increase forest cover 20% by 2021.

2.8. National Land Use Policy, 2001

The Ministry of Land has prepared the National Land Use Policy (NLUP) to fill-up an important policy gap in the country. The NLUP deals with land uses for several purposes including agriculture (crop production, fishery and livestock), housing, forestry, industrialization, railways and roads etc. The Land Use Policy aims to ensure land use synchronization with the natural environment. The policy introduced a 'zoning' system in order to ensure the best use of land in different parts of the country according to their local geological differences to logically control the unplanned expansion of residential, industrial and commercial constructions. The main areas of land use in Bangladesh are agriculture, housing, forests, rivers, irrigation and sewerage canals, ponds, railways, commercial and industrial establishments, tea estates, rubber fields, horticulture gardens, the coastal belt, sandy riverbeds and char areas (MoEF, 2005). Agricultural land is limited and is reducing about 1% per annum (MoEF, 2012). However, future growth of this sector will depend on the increment of the fertility of the land and efficiency of the irrigation. Also fallow land should be taken into consideration to expand the harvested crop land area. Urban growth rate is so alarming and has grown from 5% in 1961 to 25% in 2005. Therefore, the target is to reduce the burden of urban environment, decentralize the urban infrastructure and expand urban area with efficient urban planning and provide better urban facilities by 2021 (MoEF, 2012).

Chapter 3 Methodology of the study

This chapter represents the methodology of current research work, which will be a plausible approach to develop LCS in Bangladesh. Fig. 3.1 shows overall methodological research framework of this study which includes seven steps.

Building LCS in Bangladesh requires an accord involving all ministries and multiple stakeholders on achievable long term development path that will allow the country to maintain its growth targets while emitting less GHG than could have expected under previous development plans. In other words, LCS development involves agreements across the entire economy. Modeling illustrates each sector, such as energy sector (residential, commercial, industrial, transport and power sectors) and agriculture, forestry and land use of the country which aligned in which they are developing, the impact of this development on the level of GHG emission and the resources needed for mitigation. On the basic of fore mentioned background and information, it can be argued that the most appropriate modeling framework to develop a LCS typically involves:

- Based on explicitly established macroeconomic projection on population, GDP, industrial structure, and other macroeconomic variables for target year.
- Establishment of base year quantification of socio-economic sectors which is very useful to explore the possibility of creating future scenario for the country where the impact of development objectives and national strategies relating to GHG emission mitigation can be assessed.
- Creation of a scenario named Business as Usual (BaU) that focuses on current development plans while projecting the future scenario. This scenario represents a continuation of the current trend in national economic policies without implementing additional GHG emission mitigation countermeasure.
- Development of a scenario named Countermeasures (CM) scenario which reduces GHG

emission. This reflects the future in which there would be a lower GHG emission level through promotion of the diffusion of countermeasures.

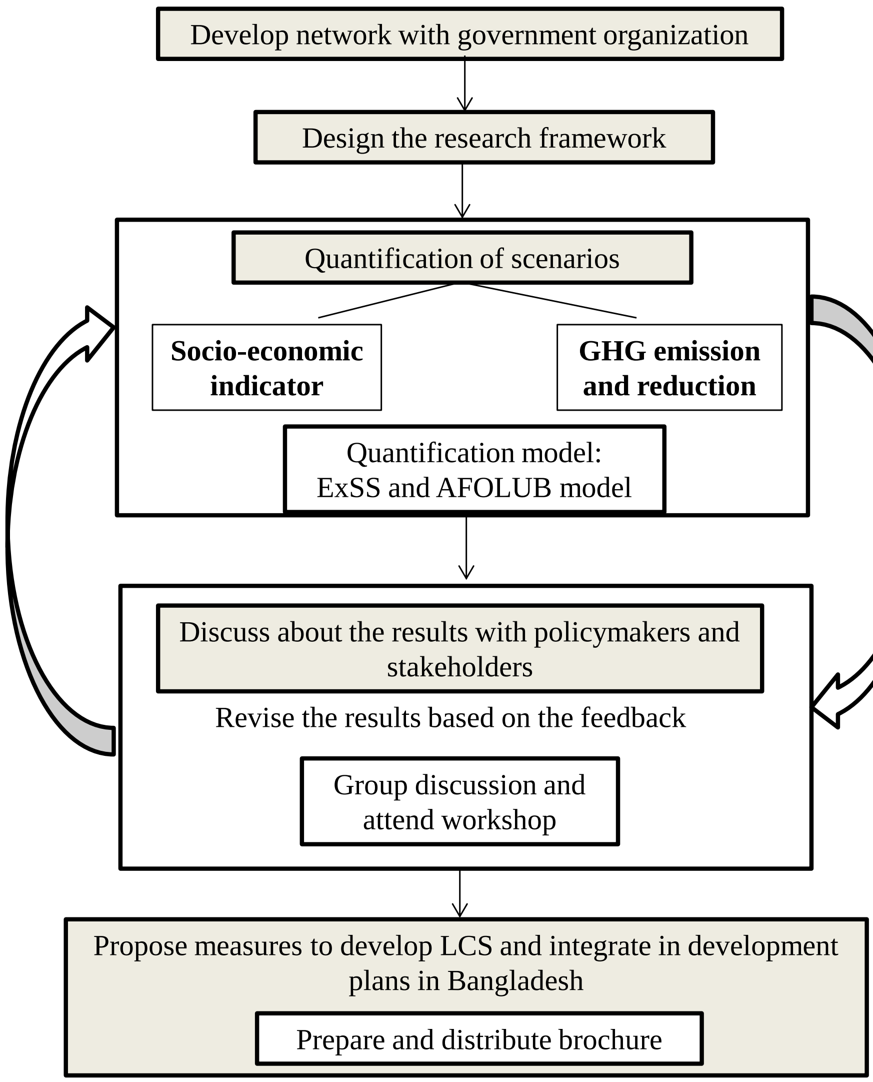


Fig. 3.1 Methodological framework

3.1 Methodology of Low- Carbon Society (LCS) study

The outline of the problem establishment of LCS study is shown in Fig. 3.2. In this study, the socioeconomic assumption of the target year, GHG emission, and measures for reduction are collectively called "LCS scenario". Socio-economic assumptions are considered as given, and then reduction measures are introduced to reduce the emission. The suitable and concrete kind of action, which needs to be taken in the country, can be identified, by comparing the future LCS scenario with BaU (business as usual) scenario. In this study, Extended Snapshot (ExSS) and Agriculture, Forestry and Other Landuse Bottom-up (AFOLUB) model are used to estimate GHG emission and mitigation potential in energy and AFOLU sectors of Bangladesh, respectively. ExSS estimates socio-economic activity level, energy demand, CO_2 emission and reduction potential through reduction measures. AFOLUB projects future GHG emission from AFOLU sectors and estimates mitigation potential under several constraints for mitigation costs.

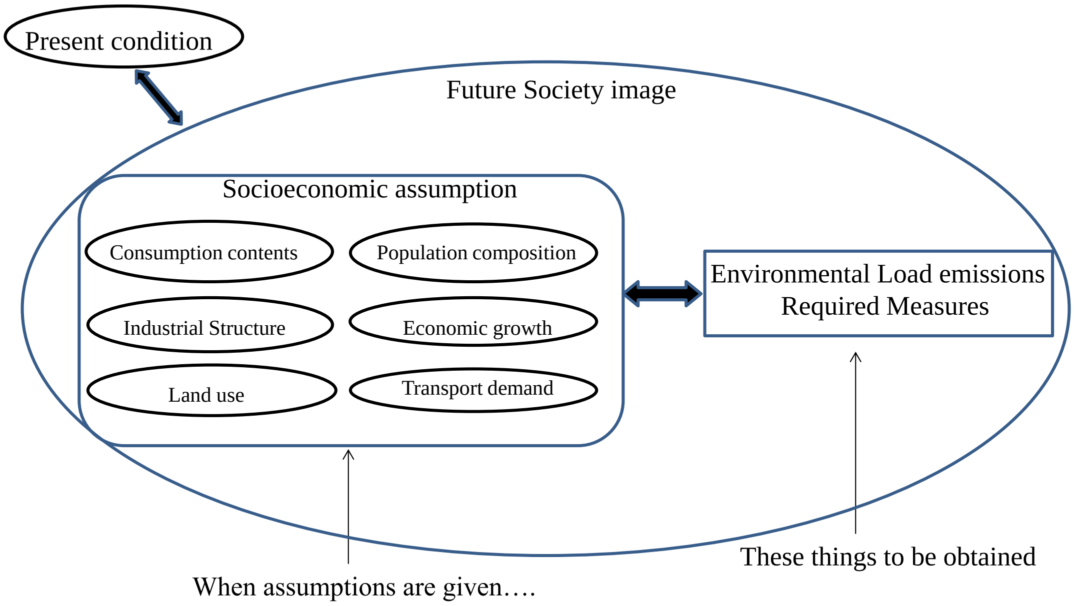


Fig. 3.2 Outline of the problem establishment of LCS study

3.2 Overview of ExSS

In order to formulate quantitative information of macro-socioeconomic and environmental variables for developing LCS scenario, Extended Snapshot Tool (ExSS) is applied. Fig. 3.3 shows overview of the study using ExSS.

The methodology applied in energy sector includes:

1) Quantification of socio-economic activity level in 2025;

2) Estimation of future energy demand and GHG emission based on socio-economic assumptions in 2025;

3) Projection of possible reduction in GHG emission though applying low-carbon measure;

Using the above model, the “future GHG emission” is projected based on two scenarios:

1) In 2025BaU, continue of existing energy efficiency without applying any low-carbon measure and

2) In 2025CM, consider the present and future availability of fossil-fuel sources with applying some reduction measures to reduce GHG emission.

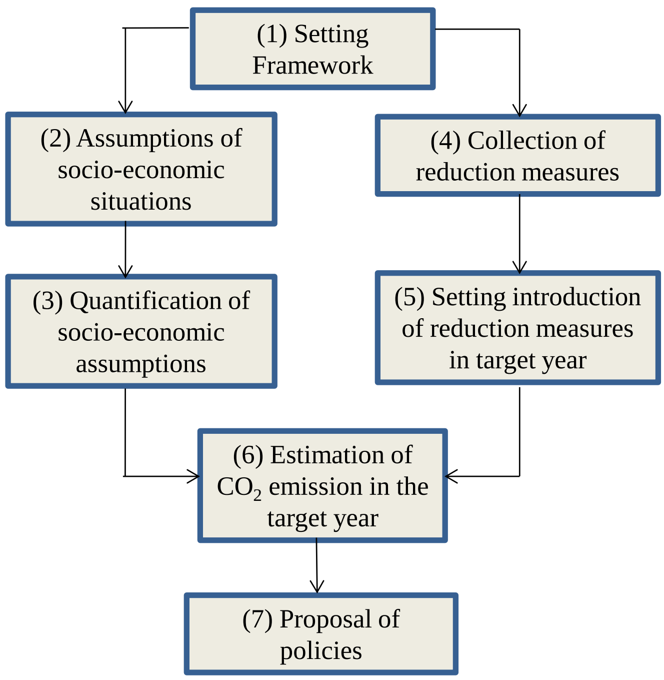


Fig. 3.3 The overview of ExSS

3.2.1 Setting framework

Framework of a LCS scenario includes; target area, base year, target year, environmental target and number of scenarios. Among them, the base year is compared with target year. The target year should be far enough to realize required change, and near enough to imagine the vision for the people in the region.

3.2.2 Assumption of socio-economic situation

Before conducting quantitative estimation, qualitative future image should be written. It is an image of lifestyle, economy and industry, land use and so on.

3.2.3 Quantification of socioeconomic assumptions

To estimate Snapshot based on the future image of (2) (Fig. 3.3), values of exogenous variables and parameters are set. Table 3.1 shows the input parameters of ExSS tool.

Table 3.1 The input parameters of socio-economic assumption in ExSS

Data	Unit
Demography	
Population by household type and age cohort	number
Persons per household by household type	number
Transport demnad	
Modal share of passenger transport	ratio
Average trip distance of passenger Transport	km
Trip per person per day	number
Freight generation per industrial output	monetery
Modal share of freight transport	ratio
Average trip distance of passenger Transport	km
Economy	
Final demand by final demand sector	monetery
Input coefficient	ratio
Import ratio	ratio
Energy demand	
Energy service demand per driving force	*
Power supply	thermal unit
Energy efficiency of applied measure	
Fuel efficiency of transport mode	
Passenger	persons-km/energy
Freight	ton-km/energy
Air conditioner, Hot water, Home electric appliances	COP (coefficient of performance)
industrial technologies	production/energy
Renewable energy	thermal unit
CO_2 emission factor	
CO_2 emission factor by primary fuel	tC/toe

*Energy service demand per driving force, the unit depends on the service and sectors. Units of sectors are number of household (residential), square km (commercial) and monetary (industry).

Using those inputs, ExSS calculates socio-economic indices of the target year such as population, GDP, output by industry, transport demand and so on. Parameter setting for the target year requires base year parameters as references.

3.2.4 Collection of reduction measures

To collect countermeasures which are thought to be available in the target year. For example, high energy-efficiency devices, transport structure change such as public transport, use of renewable energy, energy saving behavior and carbon sink. Technical data is required to estimate their effect to reduce GHG emission. This research work employed the reduction measure showed in preceding study (Japan's study).

3.2.5 Setting introduction of measures in the target year

Technological parameters related to energy demand and CO_2 emission and energy efficiency, are defined.

3.2.6 Estimation of CO_2 emission in the target year

Based on socio-economic indices and assumption of measures' introduction, GHG emission is calculated.

3.2.7 Proposal of policies

Propose policy set to introduce the measures defined. Available policies are depended on the situation of the country. ExSS can calculate emission reduction of each counter measure. Therefore, it can show reduction potential of reduction measures which especially need local policy. It can also identify measures which have high reduction potential and therefore important.

3.3 Calculation flow of ExSS

The general calculation flow of ExSS system is as follows:

- Based on given final demand and input coefficient matrix, IO analysis calculates output by industry
- Transport demand including passenger and freight transport is estimated from population and output of industry.
- Energy demand is estimated from driving forces, for example, household number, and output of industry, transport demand and assumptions of applied technologies/low carbon countermeasures.
- Based on estimated final energy demand and assumptions of power generation, primary energy demand and CO_2 emission are calculated.

3.4 Quantitative estimation tool "Extended Snapshot Tool"

ExSS is a designing tool of a future society rather than a projection of likely future. Its structure is highly flexible to design a wide range of future societies. However, the results mainly depend on input parameters, since endogenous variables are interconnected through parameters; the results are always internally consistent. Fig. 3.4 shows the structure of ExSS with input parameters, exogenous variables and variables. ExSS is formulated as a system of simultaneous equations. Given a set of exogenous variables and parameters, results is uniquely defined. In this study, only CO_2 emission from energy consumption is calculated, even though, ExSS can be used to estimate other GHG and environmental loads such as air pollutant. To determine output of industries, input-output approach is applied.

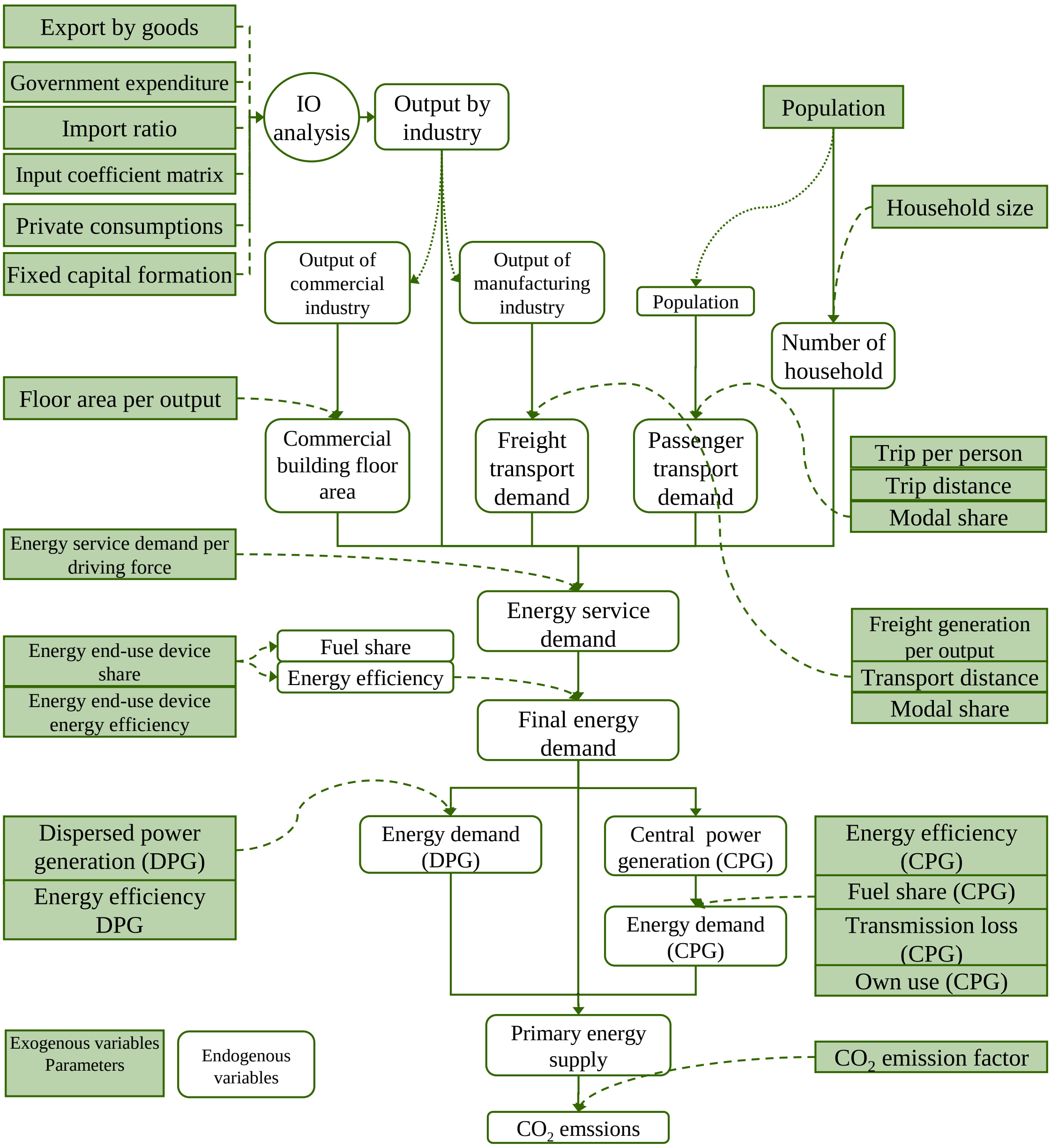


Fig. 3.4 Structure of ExSS

For future estimation, assumption of export value is especially important if the target region is thought to (or, desired to) develop led by particular industry, such as automotive manufacturing or sightseeing. Passenger transport demand is estimated from the population and freight transport demand whereby it is a function of output by manufacturing industries. Floor area of commerce is determined from output of tertiary industries. Other than driving force, activity level of each sector, energy demand by fuels determined with three parameters. They are energy service demand per driving force, energy efficiency and fuel share. Diffusion of countermeasures changes the value of these parameters, and GHG emission.

3.5 AFOLU Bottom-up Model

The AFOLUB model is a bottom-up type model for calculating GHG emission and mitigation potentials in AFOLU sectors at the national/regional level, based on detailed information of specific mitigation technologies. The model illustrates amounts and combination of GHG mitigation technologies to be applied by agricultural producer's (i.e. farmers) under economic rationality. The amounts and combinations of technologies are calculated, to ensure that the producers select the technologies in order to maximize the annual profit in agriculture sector and to maximize mitigation potential in the land use sector. The AFOLUB model solves the optimization calculation based on future assumptions of agricultural production and land use change. The methodology includes 1) projection of agricultural harvested area, livestock number and area of land use pattern; 2) quantification of GHG emission based on above projection trend on agriculture, livestock and land use condition; 3) estimation of GHG emission mitigation potential under several emission taxes. The AFOLUB model consists of two modules; Agriculture Bottom-up (AG/Bottom-up) and Land Use change Bottom-up (LU/Bottom-up).

3.5.1 AG/ Bottom-up model

The AG/Bottom-up module (Fig. 3.5) calculates GHG emission, combination of mitigation technologies and their mitigation in agricultural production and energy consumption of agricultural machines.

This module is based on the assumption that producers produce commodities to supply the amount of productions given exogenously. The term "technologies application" is divided into several periods and the producers select ways of producing commodities and combinations of mitigation technologies in order to maximize their profit. The profit is defined by benefit – cost + benefit by bioenergy sales. Production is calculated as a multiplication of productivity (i.e. crop production per unit area and carcass weight) and quantity of activity (area of cropland and number of livestock animal). There is a linkage between production and activity yields. Yields are defined as production of commodities per unit activity. It is, for example, crop production per unit area harvested and carcass weight of livestock animals. It is taken into account that yields may change due to application of countermeasures. For example, yield may decrease by fertilizer reduction and carcass weight of livestock animal may increase by improvement of feed systems. The model takes into account impacts of climate conditions on crop yields.

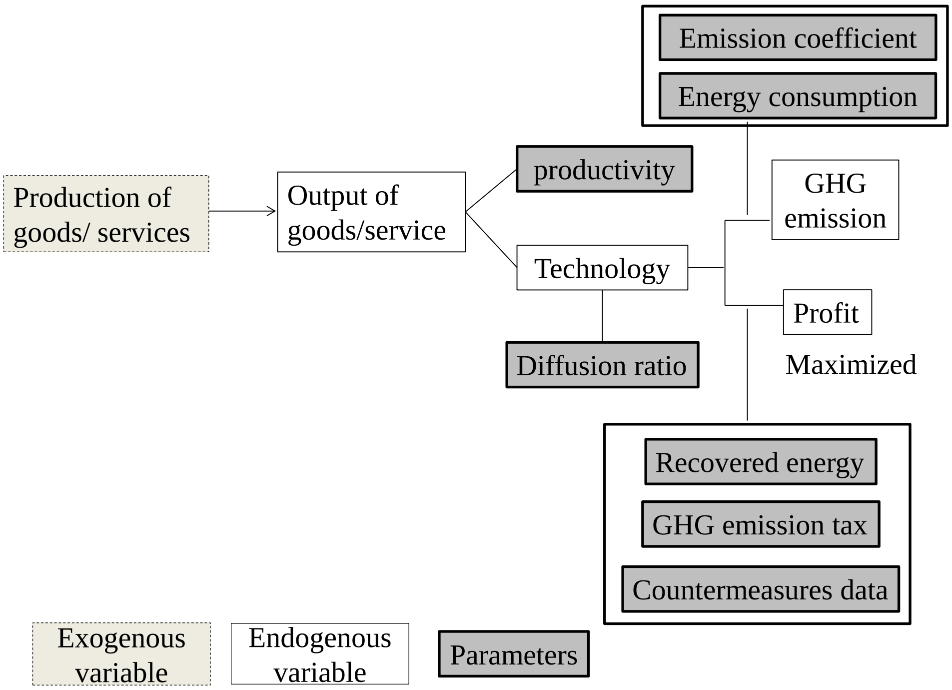


Fig. 3.5 Framework of AG/bottom-up module

3.5.2 LULUCF/Bottom-up model

The LULUCF/Bottom-up (Fig. 3.6) module calculates GHG emission and the mitigation potentials in land use sectors. The emission is caused by carbon stock change, fires and natural disturbance. Assumption of future land use change is given exogenously. The

LU/Bottom-up does not take into account benefit from activity (i.e. improved land use and wood harvesting). The module calculates total mitigation potential in an assumed period since mitigation impacts of some technologies last in the long term after application. As a scheme for technology selection in LU/Bottom-up, i prepared a typical and contrastive optimization scheme which has two conditions; a time span to be concerned in decision making and a viewpoint to evaluate mitigation effects and costs. For a time span to be concerned in decision making, i assumed a recursive calculation. This means a technology selection at every year in order for maximization of annual mitigation under annual cost constraint assumed.

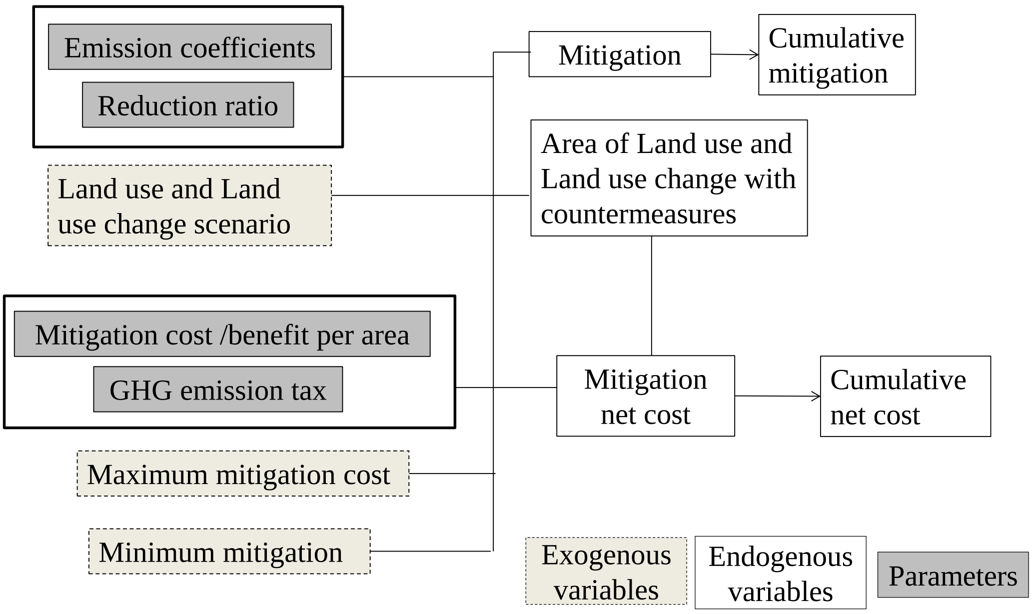


Fig. 3.6 Framework of LULUCF/Bottom-up module

As a viewpoint to evaluate mitigation effects and costs, i assumed a present viewpoint. From the viewpoint, mitigation effects and costs only in a present term are taken into consideration in the technology selection. The technologies are selected under a known budget for the present term, and cost and mitigation effects for the future are not taken into account.

3.5.3 Input and output data

Fig. 3.7 shows input data to AFOLUB model (Hasegawa and Matsuoka, 2012) is as; i) list of GHG mitigation technologies, ii) characteristics of each technology, iii) scenario of future production of agriculture, yield, livestock and land-use change, iv) assumptions of commodity and energy prices, v) production technologies, manure management systems and their economic characteristics and finally, vi) GHG emission reduction incentives. Based on the above information, mitigation technologies to be applied to reduce emission are evaluated. Target GHG in the study are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The sources of the emission of CO_2, CH_4 and N_2O are shown in Table 3.2. Ruminant animals cause CH_4 emission by enteric fermentation (3A1, IPCC inventory emission category code) and manure of livestock animals cause CH_4 emission due to anaerobic conditions (3A2). In a process of manure management, manure cause N_2O emission (3A2). Part of manure is applied on pasture, range and paddock or on croplands as organic fertilizer. N_2O emission from nitrogen derived manure is classified as emission from managed soils (category: 3C4 to 3C6). CH_4 emission comes from wetland rice fields, and N_2O emission comes from nitrogen fertilizer on croplands. In this study, nitrogen fertilizer per area of each crop is estimated by using cross-entropy methodology (Golan et al. 1996) using total fertilizer consumption (MoEF, 2012).

In estimation of emission in AFOLU sectors, emission factors are based on IPCC inventory guideline (2006) but are adjusted based on the base year emission reported in MoEF (2010). LULUCF sector is considered as a source of both emission and sink of carbon.

Table 3.2 GHG emission sources in AFOLUB model

Emission sources	Classification	Gases	IPCC Category[1]
Enteric fermentation	Dairy cattle, Other cattle, Buffalo, Sheep, Goat	CH_4	3A1
Manure management	Dairy cattle, Other cattle, Buffalo, Sheep, Goat, Chicken and Duck	CH_4, N_2O	3A2
Land use, landuse chages and forestry (LULUCF)	Forestland, cropland, grassland, wetland and otherland	CO_2	3B
Aggregate sources and Non-CO_2 emission sources on land	Emission from biomass burning[2]	CO_2	3C1
	Limimg[2]	CO_2	3C2
	Urea application[2]	CO_2	3C3
	Direct N_2O emission from managed soils	N_2O	3C4
	Indirect N_2O emission from soils	N_2O	3C5
	Indirect N_2O emission from manure management	N_2O	3C6
Rice cultivation		CH_4	3C7

Note: 1] Emission categories of IPCC (2006), 2] Gray part is not estimated in this study. Source: Hasegawa and Matsuoka (2012)

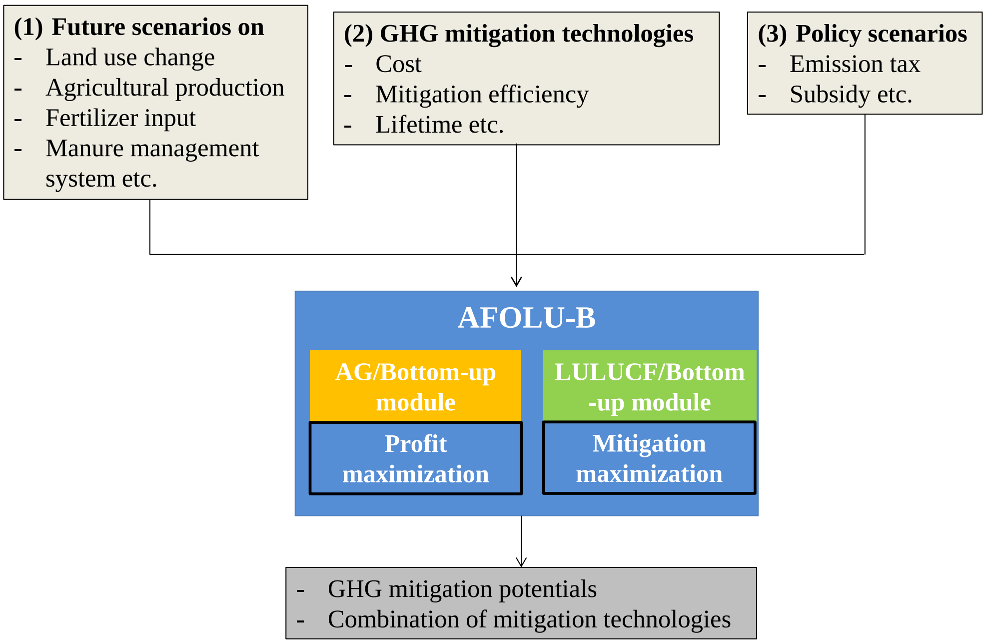


Fig. 3.7 Input and output of the AFOLUB model

3.6 Framework of the future society image description

This section defines frame work of this study.

3.6.1 Base Year and Target Year

This study considered 2005 as base year and 2025 as target year.

3.6.2 Assessed Scenarios

Two scenarios, BaU (without applying reduction measures) and CM (applying reduction measures), are conducted to assess GHG emission and reduction in Bangladesh.

3.6.3 Targeted GHGs

The targeted GHGs are CO_2, CH_4 and N_2O emitted from energy and AFOLU sectors of Bangladesh.

3.6.4 GHG Emission Reduction Target

The potential reduction of GHG emission in 2025CM compared to 2025BaU by adopting feasible reduction measures for Bangladesh. Since there is no GHG emission reduction target in Bangladesh so far. In this study, no specific GHG emission reduction target was determined. Instead, as mentioned above, potential of GHG emission reduction is projected. Therefore, it will provide important information for government of Bangladesh to specify the target of GHG emission reduction target and formulate concrete climate change policy.

3.6.5 Sectors of Activity

Residential sector, commercial sector, industry sector, passenger transport sector, freight transport sector, power sector, agriculture sector and landuse changes sector in Bangladesh are considered as sectors of activity in this study.

Chapter 4 Data collection and parameter estimation

This chapter aims on developing base-year scenario from which it will be possible to forecast the future society considering development objectives and national strategies relating to GHG emission reduction for the country. Therefore, socio-economic and energy data of base year are collected and estimated. The use of the data list on socio-economic is shown in Appendix 1.

4.1 Energy sector: Processing of input-output (IO) table

As Input-output table (IO table) in 2005 of Bangladesh is not published, it was estimated from available economic data. The outline of estimation procedure is shown in Fig. 4.1.

1) The input-output table of Bangladesh in 2000 was collected and processed.
2) The Bangladesh IO table in 2005 was estimated from (1) and economic information in 2005 by cross-entropy method.

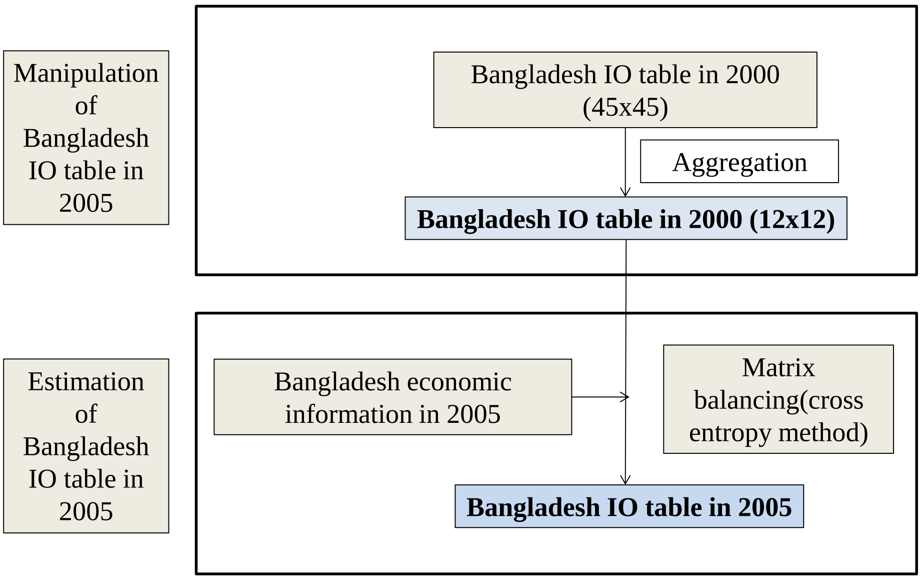


Fig. 4.1 The estimation procedure of IO table 2000 to 2005

4.2 Processing of the Bangladesh 2000 IO table

The IO table of Bangladesh in 2000 (non-competitive import type, 45 sectors) was processed into competitive import type and aggregated into 12 sectors.

4.2.1 Processing to competitive import type

Collected IO table 2000 of Bangladesh was non-competitive import type and rearranged to form the competitive import type IO table according to the procedure.

4.2.2 Aggregating the sectors

The IO table 2000 of Bangladesh was composed of 45 sectors. The number was too large for the purpose of LCS study at this stage, so it was aggregated into 12 sectors according to the industrial classification made in National accounts statistics (Bangladesh Bureau of Statistics, 2009) shown in Table 4.1. However, in this case “hotels and restaurants” and “community, social and personal services” were aggregated in “other services” and “education” and “health and social work” were in “education and health”.

4.3 Estimation of the Bangladesh 2005 IO table

The Bangladesh IO table 2005 was estimated by using aggregated IO table 2000 and economic information (e.g. gross domestic production, private consumption, government consumption, import, export) in year 2005 from National accounts statistics (Bangladesh Bureau of Statistics, 2009). The estimation procedure is shown in Fig. 4.2. The estimation was done by using General Algebraic Modeling System (GAMS) program.

4.3.1 Collection of the economic data in 2005

The Bangladesh IO table 2005 is estimated from the aggregated IO table 2000 and the economic data in 2005 such as value added, export, import, private consumption and government consumption from Bangladesh Bureau of Statistics (2009).

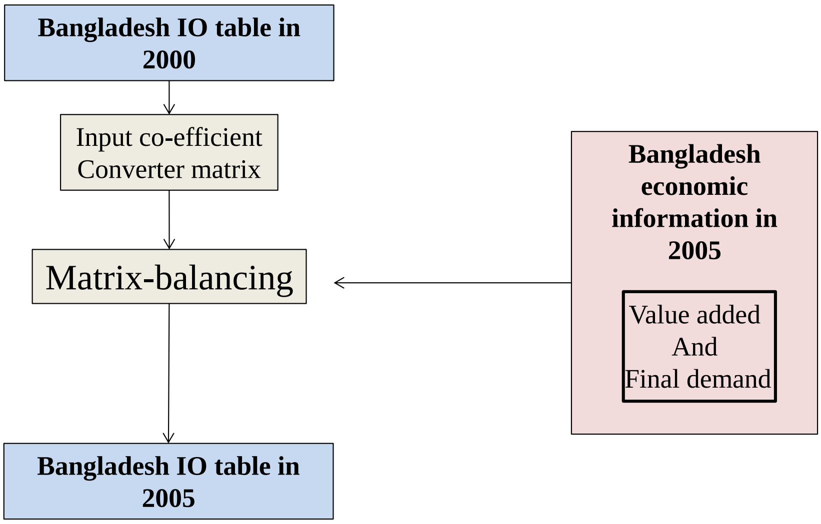


Fig. 4.2 The procedure of estimation of Bangladesh IO table

Correspondence with the value and classification of aggragation of the diffenrent industrial sectors of IO table in 2000 is shown in Table 4.1.

The estimation of input value of intial value of IO table in 2005 is shown below,

- **Value added**

The value added in 2005 was collected from Bangladesh Bureau of Statistics, 2009 and considered as the initial value of value added.

- **Domestic product (control total)**

The value of the domestic product containing intermidiate input in 2005 was not acquired from the statistics. Thus, it was estimated from value added and rate of value added and domestic product of each industry in IO table 2000.

- **Final demand**

Each total amount of private consumption expenditure, government consumption expenditure, gross domestic fixed capital formation, export and import in 2005 were collected from Bangladesh Bureau of Statistics (2009).

Table 4.1 Classification of aggragation of the industrial sectors in IO table 2000

12-sectors classification in aggregated IO table 2000		45-sectors classification in original table 2000	
Code	Sector	Code	Description
01	Agriculture and forestry	1	Paddy
		2	Grains
		3	Jute
		4	Commercial Products
		5	Tea
		6	Other crops
		7	Livestock
		8	Poultry
		10	Forestry
02	Fishing	9	Fishing
03	Minning and Quarrying	26	Petroleum Products and Natural
04	Manufacturing and Commercial goods	11	Rice milling
		12	Flour milling
		13	Other manufacturers
		14	Manufacturing of tea products
		15	Leather goods
		16	Jute textile
		17	Yarn
		18	Mill cloths (all kinds)
		19	Clothing
		20	Readymade garments
		21	Manufacturing of tobacco
		22	Products of wood
		23	Printing and publishing house
		24	Manufacture of chemicals
		25	Fertilizer, pesticides
		27	Clay materials
		28	Cement
		29	Iron and Steel basics
		30	Machinery, equipment
		31	Miscellaneous industry
05	Construction	32	Urban Building
		33	Rural Building
		34	Construction
06	Electricity, gas & water	35	Utility (Electricity,gas, water)
07	Wholesale and retail trade	36	Trade services
08	Transport services	37	Transport services
09	Real estate & renting business	38	Housing
10	Education and Health	39	Health
		40	Education
11	Government services	41	Public administration
12	Other private services	42	Other services
		43	Hotels, restaurants
		44	Communication services
		45	Information technology and services

- **The items of an intermidiate input and final demand**

The intermidiate input was computed by multipling above mentioned domestic product by the input coefficient in IO table 2000. The amount of goods of final demand were computed by multipling the total amount of each final demand sector by the share distribution by goods in IO table 2000.

4.3.2 Adjustment calculation of IO table 2005 estimation

Since the supply and demand is not balanced in initial IO table in 2005 above, it is necessary to correct by adjustment calculation. A cross-entropy method was used in adjustment calculation under input values and constraints, it formulized as a nonlinear programming problem which makes an objective function the minimum. The constraints and objective functions are explained below:

- **Constraints**

The sum total of a row and the sum toatl of a column (demand and supply) are in agreement.

$$\sum_i X_{i,k} = \sum_j X_{k,j} \times \mathrm{n}_{k,j} \tag{4.1}$$

$X_{i,j}$: IO table (estimated), $\mathrm{n}_{k,j}$: a matrix which is -1 in columns of imports and 1 in others, i: row elements of IO table, j: column elements of IO table , k: industry ($k \in i$)

The maximum of import (import does not exceed domestic demand)

$$IM_k = \sum_1 X_{k,1} \times \sum_{df} X_{k,df} \tag{4.2}$$

IM_k : imports of goods k, df: domestic final demand sector ($df \in j$), l : industry sector ($l \in i$)

The maximum of exports (exports does not exceed domestic product)

$$EX_k < \sum_j X_{k,j} \tag{4.3}$$

EX_k : exports of goods k

- **Objective function**

The sum total *df* deviation from the share distribution of the column element of the 2000 IO table, deviation from share distribution of the final demand item pf the table and deviation from an input value shall be made into the minimum. An objective function is shown below, ω_1 toω_4 is the weight of each term.

$$\min \omega_1 \sum \sum_{i=1} p_{i,j} \ln \frac{p_{i,j}}{q_{i,j}} + \omega_2 \sum_f u_f \ln \frac{u_f}{v_f} + \omega_3 \sum_l \varepsilon l^2 + \omega_4 \sum_f \varepsilon f^2 \tag{4.4}$$

The contents of each term are explained below.

The relative entropy (Kullback-Leibler divergence) of the share distribution in the column of each element in each column.

$$\sum_i \sum_j p_{i,j} \ln \frac{p_{i,j}}{q_{i,j}} \tag{4.5}$$

$$p_{i,j} = \frac{X_{i,j}}{\sum_i X_{i,j}} \tag{4.6}$$

$$q_{i,j} = \frac{Z_{i,j}}{\sum_i Z_{i,j}} \tag{4.7}$$

$p_{i,j}$: share distribution of the column element of estimated IO table

$q_{i,j}$: share distribution of the column element of the Bangladesh IO table 2000.

$z_{i,j}$: the Bangladesh 2000 IO table.

-The cross-entropy of the distribution of each final demand sector to the whole final demand.

$$\sum_f u_f \ln \frac{u_f}{v_f} \tag{4.8}$$

$$u_f = \frac{\sum_i X_{i,f}}{\sum_i \sum_f X_{i,f}} \tag{4.9}$$

$$v_f = \frac{\sum_i Z_{i,f}}{\sum_i \sum_f Z_{i,f}} \tag{4.10}$$

$u_{i,j}$: share distribution of the final demand of estimated IO table.

$v_{i,j}$: share distribution of the final demnad of the Bangladesh 2000 IO table.

The rate of change from an initial value.

εis raised to the power of two because it may become a negetive value,

$$\sum_1 \varepsilon_1^2 \tag{4.11}$$

$$\sum_f \varepsilon_f^2 \tag{4.12}$$

$$\sum_1 X_{av,1} = d_1(1+\varepsilon_1) \tag{4.13}$$

$$\sum_j X_{f,j} = d_f(1+\varepsilon_f) \tag{4.14}$$

d_l : The statistics of value addaed,

ε_l: The rate of change of an estimated value from the initial value,

d_f : The statistics of final demand,

ε_f: The rate of change of an estimated value from the initial value,

av : value added sector (av∈i).

The aggregated IO table 2000 and estimated IO table 2005 are shown in Table 4.2 and Table 4.3 respectively.

Table 4.2 IO table 2000 (billion taka), (1/2)

Description	Agriculture and forestry	Fishing	Minning and Quarrying	Manufacturing	Construction	Electricity , gas & water	Wholesale and retail trade	Transport services	Real estate & renting business	Education and Health	Government services	Other private services	Total intermediate consumption
Agriculture and forestry	163	2	0	429	26	0	0	0	0	0	0	15	635
Fishing	0.4	15	0	44	0	0	0	0	0	0	0	2	61
Minning and	10	5	4	25	6	5	7	8	13	1	2	9	96
Manufacturing and Commercial goods	112	40	10	363	107	15	29	41	29	15	7	49	816
Construction	5	0	2	8	2	1	4	12	6	1	1	3	45
Electricity, gas & water	1	2	4	31	15	7	0	3	1	0	0	1	65
Wholesale and retail trade	86	31	16	265	0	12	0	0	0	0	0	0	410
Transport services	37	0	15	136	8	10	10	8	0	0	2	1	227
Real estate & renting business	1	1	6	27	0	1	14	13	20	2	1	14	102
Education and Health	11	0	0	0	0	0	0	0	0	0	4	2	16
Government services	2	0	2	8	2	1	3	3	5	0	1	3	29
Other private services	25	5	7	68	14	9	14	19	26	9	12	70	277
Total Intermediate Input	454	100	67	1,403	180	58	82	109	99	28	30	169	2,780
Labour	129	18	6	207	86	9	205	113	102	50	69	146	1,141
Land	188	42	0	0	0	0	0	0	0	0	0	0	230
Capital	0	0	11	296	124	24	123	75	83	31	26	82	875
Indirect Tax	0	0	3	22	3	8	0	0	0	0	0	4	41
Value Added	317	61	19	524	213	42	329	187	186	81	95	232	2,287
Total Gross Input	772	160	86	1,928	393	100	410	296	285	109	126	402	5,067

Table 4.2 IO table 2000 (billion taka), (2/2)

Description	Private consumption	Government consumption	Gross domestic capital formation	Export	Import	Final Demand	Total Gross Output
Agriculture and forestry	185	0	5	9	-63	136	772
Fishing	69	0	15	15	0	99	160
Minning and Quarrying	56	0	-5	1	-62	-10	86
Manufacturing and Commercial goods	1,050	0	168	274	-381	1,112	1,928
Construction	0	0	348	0	0	348	393
Electricity, gas & water	39	0	0	0	-4	35	100
Wholesale and retail trade	0	0	0	0	0	0	410
Transport services	58	0	0	11	0	69	296
Real estate & renting business	183	0	0	0	0	183	285
Education and Health	55	46	0	0	-8	93	109
Government services	23	62	0	11	0	96	126
Other private services	115	0	0	10	0	125	402
Total Intermediate Input	1,834	108	532	331	-519	2,287	5,067

Table 4.3 IO table 2005 (billion taka), (1/2)

Description	Agriculture and forestry	Fishing	Minning and Quarrying	Manufacturing	Construction	Electricity, gas & water	Wholesale and retail trade	Transport services	Real estate & renting business	Education and Health	Government services	Other private services	Total intermediate consumption
Agriculture and forestry	335	4	0	810	49	0	0	0	0	0.4	0	31	1,230
Fishing	1	42	0	164	0	0	0	0	0	0	0	5	212
Minning and Quarrying	25	13	11	72	12	6	14	21	26	3	3	22	228
Manufacturing and Commercial goods	172	95	24	374	174	19	47	84	49	32	10	89	1,166
Construction	6	0	4	4	3	1	5	22	9	1	1	5	61
Electricity, gas & water	1	5	8	22	22	9	0	6	1	0	0	2	77
Wholesale and retail trade	161	78	39	408	0	15	0	0	0	0	0	0	701
Transport services	85	0	37	317	15	13	20	20	0	0	3	2	512
Real estate & renting business	3	1	14	38	0	1	25	29	36	4	2	28	180
Education and Health	43	0	0	0	0	0	0	0	0	0	6	5	54
Government services	0	0	3	0	1	1	1	2	3	1	1	1	12
Other private services	54	13	16	139	26	11	27	46	48	20	16	150	566
Total Intermediate Input	886	251	157	2,347	301	76	139	229	170	61	42	339	4,999
Labour	234	47	13	274	144	12	352	248	177	109	91	286	1,986
Land	340	107	0	0	0	0	0	0	0	0	0	0	447
Capital	0	0	26	392	206	32	210	164	145	69	35	160	1,439
Indirect Tax	0	0	6	29	5	11	1	0	0	0	0	9	61
Value Added	574	154	46	695	355	54	563	412	322	178	125	454	3,933
Total Gross Input	1,459	405	203	3,042	656	131	701	641	492	239	168	793	8,932

Table 4.3 IO table 2005 (billion taka), (2/2)

Description	Private consumption	Government consumption	Gross domestic capital formation	Export	Import	Final Demand	Total Gross Output
Agriculture and forestry	326	0	9	21	-127	230	1,459
Fishing	130	0	28	34	0	192	405
Minning and Quarrying	104	0	-8	3	-123	-25	203
Manufacturing and Commercial goods	1,738	0	294	626	-782	1,876	3,042
Construction	0	0	596	0	0	596	656
Electricity, gas & water	63	0	0	0	-8	54	131
Wholesale and retail trade	0	0	0	0	0	0	701
Transport services	104	0	0	26	0	130	641
Real estate & renting business	312	0	0	0	0	312	492
Education and Health	111	90	0	0	-16	185	239
Government services	19	114	0	22	0	155	168
Other private services	204	0	0	24	-1	227	793
Total Intermediate Input	3,111	204	919	756	-1,057	3,933	8,932

4.4 Transport Sector

4.4.1 Passenger transport volume

This section explains formulation of projection of passenger transport demand in ExSS and estimation of parameters in the base year, 2005. The data about the passenger transport demand of Bangladesh was collected from Bangladesh Transport Sector Review (Ministry of Communication, 2010) and some other literatures.

4.4.2 Formulation of the passenger transport model

The estimation formula of passenger transport demand is shown below. Annual passenger transport volume (million passenger-km) is estimated by multiplying population by the trip generation per person per day (trip/person/day), modal share, average trip distance (km/trip), and the days in one year (365 days).

$$PTD_{ptm} = \sum_{td}\sum_{age}\sum_{hht} Pop_{age,hht} \times Ptg_{age,td} \times Pts_{td,ptm} \times Ptad_{td,ptm} \times 365 \times (1/10^6) \qquad (4.15)$$

Where,

PTD_{ptm}: Passenger transport demand (million passenger-km)

$Pop_{age,hht}$: Population by age cohort and household type (population)

$Ptg_{age,td}$: Trip per person per day by age cohort and transport destination (passenger-trip/population/day)

$Pts_{td,ptm}$: Modal share of passenger transport (trip/trip)

$Ptad_{td,ptm}$: Average trip distance of passenger transport (km).

age: age cohort (age group 0-14, age group 15-64, age group 65^+)

ptm: passenger transport mode ($\in eds, \in esc$)

td : transport destination

The sum of "Pts" should be one, $\sum_{ptm} Pts_{td,ptm} = 1$.

4.4.3 Trip generation per person per day

The assumption of trip/person/day is shown in Table 4.4. Trip generation per person per day of the passenger transport was assumed as 2 (trip/person/day) for the estimation of transport volume of walks and bicycle in this study.

Table 4.4 Trip generation per person per day in 2005 (trip/person/day)

Age structure	Domestic
Age group 0-14	2
Age group 15-64	2
Age group 65^{+}	2

4.4.4 Modal share estimation

Modal share ($Pts_{td,ptm}$) of passenger transport by types of transport mode was collected from Bangladesh Transport Sector Review (Ministry of Communication, 2010). In that report, in 2005 the passenger transport volume was 112 billion-km (passenger) and modal share of road was 88%, railway 4% and inland water transport 8% and passenger transport volume 112 billion-km (passenger). Saidur (2005) reported that average trip distance was 44km in 1993 and transport volume share (road 75%, railway 12% and inland waterway 13%) in 2005. This study assumed that the average trip distance in 2005 is same as 1993, 44km. Total number of trips (billion) per year can be calculated by dividing the transport volume 112 billion-km with average trip distance 44 km. The total number of trips (billion) per year was then distributed in each transport mode by using the above mentioned modal share (Ministry of

Communication, 2010). Total road transport volume (million pass-km) was distributed in different transport mode by multiplying transport volume with transport volume share of each mode. Then average trip distance of each transport mode was calculated by dividing transport volume of each transport mode by number of trips per year of the mode.

Sum of trip per person per day of the three transport modes (road, railway and inland waterway) was estimated by dividing number of trips by Bangladesh population, and it was 0.05trip/person/day. The value seems too small and unrealistic to envision actual trip person per day in Bangladesh. Therefore, i considered the study does not include walk and bicycle in "road", and added walk and bicycle. As average trip/person/day was assumed 2 in 2005 already, i used the trip/person/day 0.05 to distribute road vehicle, railway and waterway modal share, and for walk and bicycle trip/person/day was 2– 0.05=1.95, both having modal share of 48.8% each. The calculation of modal share of each mode is shown in Table 4.5. The estimated result of modal share is shown in Table 4.6.

Table 4.5 Modal share calculation in 2005

Transport mode	Avg. trip/person/day*Modal share	Estimated Modal share
Railways	(0.05*0.04)/2 =	0.001
Waterway	(0.05*0.08)/2 =	0.002
Road vehicle	(0.05*0.88)/2 =	0.022
Walk	(1.95*0.5)/2 =	0.488
Bicycle	(1.95*0.5)/2 =	0.488

Table 4.6 Modal share in 2005

Mode of Transport	Road vehicle	Railway	Inland water transport	Walk	Bicycle
Modal Share	0.021	0.001	0.002	0.488	0.488

4.4.5 Average trip distance

This study assumed the average trip distance for walk and bicycle is 2.5 km and estimated average trip distance for other modes of transport (Table 4.7). Average trip distance of each mode was calculated by dividing transport volume (pass-km) with total number of trips (see formula 4.16). Number of trips per year of each transport mode was calculated by dividing total transport volume (pass-km) with average distance of all three passenger transport modes {see section 4.4 (4.4.2) and then multiplying with the modal share of each transport mode (see formula 4.17).

$$Ptad_{td,ptm} = \frac{PTD_{ptm}}{Ptr_{td}} \tag{4.16}$$

$$Ptr_{td} = \frac{PTD_{ptm}}{AD} \times \frac{Pts_{td,ptm}}{100} \tag{4.17}$$

Where,

Ptr_{td} = Number of trips (billion) per year;

AD = Average trip distance of all three passenger transport modes (road vehicle, railway, inland waterway) (44km);

$Pts_{td,ptm}$: Modal share of passenger transport (trip/trip)

Explanation of other units (see formula 4.15);

Table 4.7 Average trip distance in 2005 (km)

Mode of Transport	Road vehicle	Railway	Inland water transport	Walk	Bicycle
Average Trip Distance	37.5	132	71.5	2.5	2.5

4.4.6 Freight transport volume

The structure of the freight transport model and the parameters estimation of the base year 2005 are explained in this section. The detailed data of the freight transport volume such as transport volume, modal share in Bangladesh was taken from Bangladesh Transport Sector Review (Ministry of Communication, 2010). The freight transport volume was 20 billion ton-km in 2005.

4.4.7 Formulation of the freight transport model

The estimation formula of freight transport volume is shown below. Freight transport volume (million ton-km) is estimated by multiplying output of industry (million taka) by freight transport generation per output (ton/million taka), modal share, and average trip distance (km).

$$FTD_{ftm} = \sum_{pss}\sum_{td} PD_{pss} \times Ftg_{pss,td} \times Fts_{td,ftm} \times Ftad_{td,ftm} \times (1/10^6) \quad (4.18)$$

FTD_{ftm}: Freight transport demand [mill. ton-km]

PD_{pss}: Output of primary and secondary industry [million taka]

$Ftg_{pss,td}$: Freight generation per industrial output [ton/ million taka]

$Fts_{td,ftm}$: Modal share of freight transport [share, ton/ton, $\sum_{ftm} Fts_{td,ftm} = 1$]

$Ftad_{td,ftm}$: Average distance of freight transport [km].

pss: primary and secondary industry ($\in pds$)

ftm: freight transport mode ($\in eds, \in esc$)

4.4.8 Modal share estimation

The modal share of freight transport is the rate (tonne base) of each mode occupied to the sum total of freight transport volume. Modal share freight transport was collected from

Bangladesh Transport Sector Review (Ministry of Communication, 2010). The values were shown in Table 4.8.

Table 4.8 Modal share in 2005

Mode of Transport	Road vehicle	Railway	Inland water transport (IWT)
Modal Share	0.8	0.04	0.16

4.4.9 Freight transport generation per output

This study considered the same freight transport generation per output in all industrial sectors. Only domestic transport is considered in this study. Freight transport generation per output was computed by dividing the total freight transport volume (tonne) with the total value of output of primary industry and secondary industry. The value 0.023 (ton/million taka) was obtained (Table 4.9).

Table 4.9 Freight transport generation per output in 2005 (ton/million taka)

Industry	Domestic
Agriculture- Forestry-Fishery	0.023
Mining and quarrying	0.023
Manufacturing	0.023
Construction	0.023
Electricity and Gas	0.023

4.4.10 Average trip distance by freight mode

The average trip distance by each mode was found using the freight transport volume (ton-km) which was computed by supplement the estimation based on the formula (4.16), freight transport volume and output of industry (primary and secondary). The estimated values are shown in Table 4.10.

Table 4.10 Average trip distance by mode in 2005 (km)

Mode of Transport	Road	Railway	Inland water transport (IWT)
Average Trip Distance	158	82	115

4.5 Demographic data

The source of population related data (population by sex and age cohort, the number of households) and the number of workers by industries are described in this section.

4.5.1 Population by sex and age cohort

The data of the population in base year 2005 was collected from Statistical Yearbook of Bangladesh 2009 (Bangladesh Bureau of statistics, 2010). Population by age group by sex in Bangladesh was obtained from Gender statics of Bangladesh (Bangladesh Bureau of statistics, Ministry of Planning, 2008) and Sectoral Need-based Projections in Bangladesh (Ministry of Planning, 2006). The base year population is 139,760,000.The values of population by sex and age cohort are shown in Table 4.11.

Table 4.11 Population by sex and age cohort in 2005 (persons)

Age structure (2005)	Urban	Rural	Total
Age group 0-14	11,493,840	39,322,360	50,816,200
Age group 15-64	21,928,308	61,086,340	83,014,648
Age group 65+	1,197,852	4,731,300	5,929,152
Total	34,620,000	105,140,000	139,760,000
share	25%	75%	100%

4.5.2 The number of households

The data of households in 2001 was obtained from Bangladesh Bureau of Statistics and estimated for the base year 2005 by dividing the total population of 2005 by the number of person per household which was 4.9 in 2005. In this study, two types of households were considered based on the classification of the Statistical yearbook, 2009 (Bangladesh Bureau of Statistics, 2010), shown in Table 4.12.

Table 4.12 Household number in 2005 (number)

Household Type	Household number in 2005
Urban	7,130,612
Rural	21,391,837
Total	28,522,449

4.5.3 Number of workers by industry

The number of workers by industry was collected from Gender statics of Bangladesh, (Bangladesh Bureau of statistics, Ministry of planning, 2008), entitled as labor force survey (2005). In Bangladesh 54% of the workers are engaged in agriculture sector, 16% in the industrial sector and the rest 32% in service sector in 2005. In 2010, workers switched their job from agricultural sector and service sector to industrial sector, resulting 45% employment in agricultural sector, 30% in industrial sector and 25% in the service sector (Ministry of planning, 2010). The distribution of workers in urban and rural household is shown in Table 4.13.

Table 4.13 Number of workers by industry in 2005 (persons)

Name of the industry	Urban	Rural
Agriculture and forestry	4,918,653	41,308,202
Fishing	144,061	1,585,398
Mining and quarrying	58,085	62,495
Manufacturing	4,858,349	5,379,715
Electricity, Gas, Water	51,719	52,578
Construction	771,553	1,406,946
Whole sale and retail trade	3,924,463	5,850,074
Hotel and Restaurant	405,418	627,770
Transport, storage and communication	1,855,277	3,268,605
Bank, insurance and Finance	656,711	329,050
Real estate, rent and business	196,586	141,325
Public administration	729,666	680,689
Education service	1,223,726	1,381,905
Health and social worker	491,517	319,285
Community, social and private household	2,796,761	3,183,589

4.6 Energy balance table

4.6.1 Energy balance table of Bangladesh

In this study, total volume of energy supply and demand is taken from energy balance table 2005 (Table 4.14) (IEA, 2007). Non-energy use is not included in this study.

Table 4.14 Bangladesh Energy balance table 2005 (ktoe)

Thousand tonnes of oil equivalent / *Milliers de tonnes d'équivalent pétrole*											
SUPPLY AND CONSUMPTION 2005	Coal & peat	Crude oil	Petroleum products	Gas	Nuclear	Hydro	Geotherm. solar etc.	Combust. renew. & waste	Electricity	Heat	Total
Production	-	98	-	10806	-	111	-	8296	-	-	19311
Imports	350	1070	3249	-	-	-	-	-	-	-	4669
Exports	-	-	-87	-	-	-	-	-	-	-	-87
Intl. marine bunkers	-	-	-35	-	-	-	-	-	-	-	-35
Stock changes	-	319	9	-	-	-	-	-	-	-	328
TPES	**350**	**1488**	**3136**	**10806**	**-**	**111**	**-**	**8296**	**-**	**-**	**24187**
Electricity and CHP plants	-	-	-535	-4682	-	-111	-	-	1947	-	-3381
Petroleum refineries	-	-1488	1416	-	-	-	-	-	-	-	-71
Other transformation *	-	-	-64	-688	-	-	-	-	-261	-	-1013
TFC	**350**	**-**	**3953**	**5436**	**-**	**-**	**-**	**8296**	**1686**	**-**	**19722**
INDUSTRY SECTOR	**350**	**-**	**230**	**1526**	**-**	**-**	**-**	**-**	**707**	**-**	**2813**
Iron and steel	-	-	-	-	-	-	-	-	-	-	-
Chemical and petrochemical	-	-	-	-	-	-	-	-	-	-	-
Non-metallic minerals	350	-	-	-	-	-	-	-	-	-	350
Non-specified	-	-	230	1526	-	-	-	-	707	-	2463
TRANSPORT SECTOR	**-**	**-**	**1758**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**1758**
Aviation	-	-	288	-	-	-	-	-	-	-	288
Road	-	-	1050	-	-	-	-	-	-	-	1050
Non-specified	-	-	420	-	-	-	-	-	-	-	420
OTHER SECTORS	**-**	**-**	**1470**	**1869**	**-**	**-**	**-**	**8296**	**979**	**-**	**12614**
Residential	-	-	750	1616	-	-	-	8296	768	-	11431
Comm. and publ. services	-	-	-	159	-	-	-	-	138	-	296
Agriculture/forestry	-	-	720	95	-	-	-	-	45	-	859
Non-specified **	-	-	-	-	-	-	-	-	27	-	27
NON-ENERGY USE	**-**	**-**	**496**	**2041**	**-**	**-**	**-**	**-**	**-**	**-**	**2537**
Electricity generated - GWh	-	-	*1526*	*19824*	-	*1293*	-	-	-	-	*22643*
Heat generated - TJ	-	-	-	-	-	-	-	-	-	-	-

* Includes transfers, statistical differences, own use and distribution losses.
** Includes fishing.

4.7 Parameter estimation of energy demand

The parameter of energy demand is estimated from the value of an energy balance table of base year 2005 (Table 4.14) and several other literatures for details.

4.7.1 Formulation of the energy demand model

In ExSS, energy demand by energy demand sectors is calculated by following methods.

The estimation formula of energy demand is shown below. Energy demand is estimated by multiplying amount of activities by energy service demand per driving force, fuel share, and the reciprocal of energy efficiency.

$$ED_{eds,esc,e} = ESDF_{eds,esc} \cdot ESVG_{eds,esc} \cdot ES_{eds,esc} \cdot EE_{eds,esc,e} \qquad (4.19)$$

Where,

$ED_{eds,esc,e}$: energy demand by energy demand sector, by energy service type, and by fuel type (toe)

$ESDF_{eds,esc}$: the amount of activities by energy demand sector, by energy service type, and by sector (activity)

$ESVG_{eds,esc}$: energy service demand per driving force by energy service demand sector and energy service type (toe/activity)

$ES_{eds,esc}$: fuel share by energy demand sector and energy service type ($\sum ES_{eds,esc,e} = 1$)

$EE_{eds,esc,e}$: the reciprocal of energy efficiency by energy demand sector, by energy service type, and by fuel type ($\sum ES_{eds,esc,e} = 1$)

eds: energy demand sector

esc: energy service type

e: fuel type

The amount of activities (*ESDF*) is a socioeconomic indicator which shows the level of activity of energy demand sector; residential sector: the number of households, commercial and industry sector: output, transport sector: transport volume. Energy service means the utility acquired by using energy, and it defines as follows:

$$EF_{eds,esv,e} = \frac{ESVD_{eds,esv,e}}{ED_{eds,esv,e}} \tag{4.20}$$

$ESVD_{eds,esc}$: energy service demand by energy service demand sector and energy service type (toe)

In this study, energy efficiency of the base year (2005) is set to 1.

4.7.2 Estimation procedure of energy demand by energy service by energy type

4.7.2.1 Base year energy demand by energy type in residential and commercial sector

This section shows the procedure of estimation of residential energy demand by energy service by energy type in residential and commercial sector. Energy demand of residential sector is estimated by household type (urban and rural). Total energy demand in residential sector and commercial sector was collected from the energy balance table 2005, (IEA, 2007) (Table 4.14). From the energy balance table 2005, it was observed that, residential sector was the largest energy consumer (11,430ktoe) in the entire sectors and was the solo consumer of biomass, whereas commercial sector is the smallest energy consumer, 297ktoe.

i. Biomass consumption

Bangladesh Bureau of statistics considered two types of households (e.g. urban and rural) and household share distribution was 25% and 75% respectively in 2005. Biomass (fuel wood, non-fuel wood- e.g. crop residue and cow dung) was used mainly for cooking in this sector (Blunck, 2007). In Bangladesh biomass (wood fuel, leaves, crop residues and animal residues) is the principal form of energy used by the people, and particularly of those living in the rural areas (Kürschner, 2009). Based on this report, this study assumed that half of the urban population use biomass. Since urban population is 25% of the total population, the share of biomass consumption in urban area is assumed 12.5%. The rest of 87.5% of biomass was assumed to be consumed in rural area in 2025.

The share of biomass consumption in urban area= 25% / 2 = 12.5% (4.21)

The share of biomass consumption in rural area= 100% - 12.5% = 87.5% (4.22)

ii. Electricity consumption

In Bangladesh 38% of people had access to the electricity in 2005 (Bangladesh Power Development Board, 2006) and was mainly consumed by the urban area. This study assumed in urban area all people have access to electricity, hence, 25% out of 38% was in urban area. It means the share of electricity consumption of 65.8% and 34.2% of total electricity in urban and rural area respectively.

The share electricity consumption in urban area= 25% / 38% = 65.8% (4.23)

The share electricity consumption in rural area = 100% - 65.8% = 34.2% (4.24)

iii. Oil consumption

This study considered the share of oil consumption is same as electricity consumption because of lack of relevant data of oil demand in residential sector. The shares of oil consumption in urban and rural area are same as electricity consumption (see formula 4.22 and 4.23).

The share oil consumption in urban area = 65.8% (4.25)

The share oil consumption in rural area = 34.2% (4.26)

iv. Gas consumption

Barnes et al. (2010) reported that gas consumption share in rural area was smaller than oil consumption. Therefore, lack of actual share of gas, this study assumed that share of gas consumption in rural area was half from oil consumption share in 2025. Share of natural gas consumption in rural area was 17.1% and the rest 83.9% for urban area was calculated according.to the formula 4.24 and 4.25.

The share of natural gas consumption in rural area = 34.2% /2= 17.1% (4.27)

The share of natural gas consumption in urban area=65.8% + 17.1% = 83.9. (4.28)

4.7.2.2 Base year energy demand by energy service type in residential and commercial sector

Blunck (2007) reported that in rural Bangladeshi households, most of the energy is consumed for cooking and rice parboiling (see Fig. 4.3). Firewood, tree leaves, crop residues, and cow dung are largely used for cooking purposes, whereas kerosene and electricity are hardly ever used for cooking. Blunck (2007) calculated that rural sector of Bangladesh consumes 86%

energy for cooking and 7% for rice parboiling in this sector.

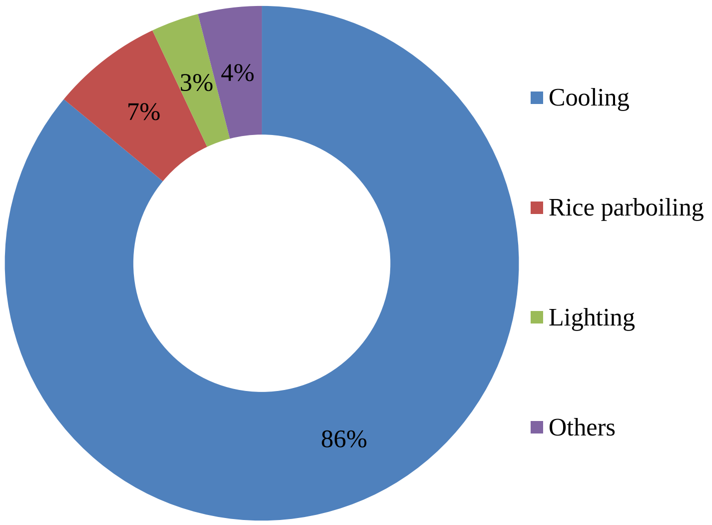


Fig. 4.3 Purposes of energy use in rural households

For urban area of residential sector, energy demand by energy service was estimated according to the share of energy demand by energy service by SAGE (EIA, 2003). Table 4.15 and Table 4.16 show the share of energy demand by energy service in residential and commercial sector respectively. Original SAGE tables for residential and commercial sector are shown in appendix 5 and 6. For rural area energy demand was calculated by share distribution of energy use in rural Bangladeshi households (Fig. 4.3). The results were shown in Table 4.17 and Table 4.18 for urban and rural area in residential sector respectively and Table 4.19 for commercial sector.

The Share of energy service demand by energy type is shown in Table 4.15 and 4.16. The energy demand in urban area by energy service is shown in Table 4.17. The energy demand for rural area was split by energy type by above mentioned formula and then using the share of energy service type in Fig. 4.3 to split the energy demand by energy type by energy service type. The energy demand in rural area by energy service is shown in Table 4.18. The commercial sector energy consumption by energy service is shown in Table 4.19.

Table 4.15 Share of residential energy service by fuel type

Energy Type/ Energy service	Hot water heating	Space cooling	Refrigerators and freezers	Cooking	Miscellaneous energy use	Lighting	Total
Natural gas	45%			40%	15%		100%
Kerosene	45%			40%		15%	100%
Biofuels	50%			50%			100%
Electiricity	10%	8%	10%	5%	25%	42%	100%

(Note: Space heating+ Hot water heating = Hot water heating; as space heating is not popular in Bangladesh, Cloth dryer + cloth washer + dish washer + other energy uses = miscellaneous energy use)

Table 4.16 Share of commercial energy service by fuel type

Energy Type/ Energy service	Hot water heating	Space cooling	Refrigerators and freezers	Cooking	Miscellaneous energy use	Lighting	Total
Natural gas	55%	0%	0%	40%	5%	0%	100%
Electiricity	9%	13%	35%	1%	20%	22%	100%

(Note: Space heating+ Hot water heating = Hot water heating; as space heating is not popular in Bangladesh, Cloth dryer + cloth washer + dish washer + other energy uses = miscellaneous energy use)

Table 4.17 Energy demand in urban area by energy service (ktoe)

Energy Type/ Energy service	Hot water heating	Space cooling	Refrigerators and freezers	Cooking	Miscellaneous energy use	Lighting	Total
Natural gas	603	0	0	536	201	0	1,340
Kerosene	222	0	0	197	0	74	493
Biofuels	518	0	0	519	0	0	1,037
Electiricity	51	40	51	25	126	212	505
Total	603	40	8,643	7,367	7,039	6,752	3,375

Table 4.18 Energy demand in rural area by energy service (ktoe)

Energy Type/ Energy service	Hot water heating	Space cooling	Refrigerators and freezers	Cooking	Miscellaneous energy use	Lighting	Total
Natural gas	43	0	0	205	28	0	276
Kerosene	64	0	0	0	52	141	257
Biofuels	552	0	0	6707	0	0	7,259
Electiricity	2	81	81	15	0	85	263
Total	660	81	81	6,927	81	226	8,055

Table 4.19 Commercial sector energy consumption by energy service (ktoe)

Energy Type/ Energy service	Hot water heating	Space cooling	Refrigerators and freezers	Cooking	Miscellaneous energy use	Lighting	Total
Natural gas	87	0	0	64	8	0	159
Electiricity	12	18	48	1	28	30	138

4.7.3 Estimation procedure of energy consumption by industry

The procedure of estimation of energy consumption by industry is shown in this section. There is only data of "Non-specified industry" sector in the energy balance table 2005, Bangladesh, (IEA, 2007). This study estimated energy consumption by each industry using information in IO table (formula 4.19). The energy consumption by fuel type by industries is shown in Table 4.20.

$$V_{e,pds} = V_e \times \frac{X_{e,pds}}{\sum_{pds} X_{e,pds}} \qquad (4.29)$$

Where,

$V_{e,pds}$: Energy consumption by each industry (ktoe);

V_e : Total energy consumption (ktoe) by energy type from energy balance table;

$X_{e,pds}$: Intermediate input of each industry (monetary) from IO table;

$\sum_{pds} X_{e,pds}$: Total intermediate input of each industry (monetary) from IO table;

e= fuel type; *pds*= industry;

Table 4.20 Energy consumption by fuel type by industries in 2005 (ktoe)

Industry/Fuel type	Coal	Oil	Gas	Biomass	Electricity	Total
Agriculture and forestry	0	674	58	0	44	776
Fishing	0	46	37	0	28	111
Minning and Quarrying	1	2	5	0	2	10
Manufacturing	340	218	1,435	0	665	2,658
Construction	9	9	76	0	35	130
Electricity, gas & water	0	2	9	0	4	15
Total	350	950	1,621	0	779	3,700

For industrial sector, too, SAGE (see Appendix 4) was used in order to split energy service demand by energy service type. Energy service demand per driving force (it is the same as the energy demanded per output since energy efficiency of the base year is set to 1) and fuel share were estimated from the energy demand obtained from the energy balance table by fuel type in industry and IO table 2005. The energy demand by energy service type of industrial sector is shown in Table 4.21.

Table 4.21 Energy demand in industrial sector in 2005 (ktoe)

	Energy service type	Coal	Oil	Gas	Biomass	Electricity
Primary Industry	Direct heat (furnace)	0	94	36	0	6
	Steam boiler	0	338	47	0	0
	Motor	0	4	0	0	56
	Other industrial energy service	0	284	12	0	9
Secondary Industry	Direct heat (furnace)	172	30	580	0	63
	Steam boiler	144	108	748	0	0
	Motor	0	0	0	0	551
	Other industrial energy service	35	92	198	0	92

4.7.4 Estimation of energy demand in transport sector

Total energy demand of the transport sector is obtained from the energy balance table 2005

(IEA, 2007). SAGE table was used to split energy demand by type of transport mode in 2005 (see table 4.22). In order to split energy demand to road and others, data of gasoline and diesel consumption was taken from IEA (2008). In order to split fuel consumption of others to railway and waterway, this study considered modal share and the ratio was 1:3. Then SAGE (EIA, 2003) was used to split the energy demand to freight and passenger (road and rail) transport. For waterway, the assumption was energy consumption for 12 pass-km, equivalent to 1 ton-km (Appendix 7).

Table 4.22 Energy demand by type of transport mode in 2005 (ktoe)

	Transport Mode	Coal	Oil	Gas	Biomass	Electricity
Passenger transport	Road vehicle	0	404	0	0	0
	Railway	0	21	0	0	0
	Inland water transport	0	105	0	0	0
Freight transport	Road vehicle	0	646	0	0	0
	Railway	0	84	0	0	0
	Inland water transport	0	210	0	0	0

4.7.5 Proposed reduction measures for energy sector

Selection of reduction measures for energy sectors is based on the overseas reports as Mizuho Information & Research Institute (2005), The Energy Conservation Center, Japan (2007) and Shiga prefecture Sustainable Society research Team, Japan (2005), to reduce the energy demand in 2025CM from 2025BaU, shown in Table 4.23.

To use quantitative estimation, gather technical data of low carbon countermeasures includes:

- Energy efficient end-use device. Household equipment, industrial equipment, vehicles, etc.
- Building. Better insulation of buildings, passive heating & cooling, etc.
- Power supply. Reduce transmission and distribution loss, lower CO_2 intensity of power generation, etc.
- Transport structure. Public transport, transport demand management, etc.

- Renewable energy. PV, solar water heater, wind power, etc. Others: energy saving behavior by general public, carbon sinks etc.

Table 4.23 List of low-carbon measures

Sector	Low-carbon measures and technologies	Specification			Source measure setting (Service type)	
Residential	Air conditioner (highest efficiency)	COP	6.60	*2	Diffusion rate (cooling)	60%
	Oil water heater (high efficiency)	COP	0.83	*1	Diffusion rate (hot water: petrolium)	(6-9)%
	Gas heater (letent heat recovery)	COP	0.83	*1	Diffusion rate (hot water: gas)	(9-40)%
	Heat pump water heater	COP	4.5	*1	Diffusion rate (hot water: electricity)	(5-6)%
	Gas stove (high efficiency)	Thermal efficiency (base year=1)	1.22	*1	Diffusion rate (kitchen:gas)	(10-40)%
	Efficiency improvement of other electric appliances	Electricity consumption (base year=1)	0.48	*1	Electricity consumption (base year=1)	0.48
	Flurorescent light (hf type)	Electricity consumption (base year=1)	1.33	*1	Diffusion rate (Fluroescent	(38-74)%
	Air conditioner cooling dedicated (highest efficiency)	COP	4.07	*1	Diffusion rate (cooling:electricity)	100%
	Gas heater (high efficiency)	COP	0.87	*1	Diffusion rate (hot water:gas)	50-100)%
	CO_2 refrigerent water heater	COP	3	*1	Diffusion rate (hot water)	25%
	Gas kitchen (high efficiency)	Thermal efficiency (base year=1)	1.15	*1	Diffision rate (Kitchen:gas)	50-100)%
Commercial	Efficiency improvement of other electric devices	Electricity consumption (base year=1)	0.41	*1	Electricity consumption (base year=1)	0.41
	Flurorescent light alternative, timer controlled	Electricity consumption (base year=1)	3.95	*1	Diffusion rate (Fluorescent	100%
	Behavior changes forenergy saving			*3		
	Cooling	Reduction rate of energy service	20%		Diffusion rate	50%
Industrial	High efficient industrial devices					
	High efficient boiler			*3	Diffusion rate	100%
	High efficient industrial furnace			*4	Diffusion rate	100%
	High efficient motor			*3	Diffusion rate	100%
	Fuel shift				Conversion ratio	(20-80)%
Passenger transport	Modal shift					
	From vehicle to bus				Conversion ratio	3%
	From vehicle to train				Conversion ratio	5%
Freight transport	Modal shift				Conversion ratio	10%
Power sector	Transmission loss reduction	Reduction rate				5.3%
	Fuel shift from fossil fuel to Nuclear	Shift rate				5%
	Fuel shift from fossil fuel to renewables	Shift rate				3%

*1 Mizuho Information & Research Institute, Inc. (2005): Report on investigation for scenario making and simulation program "Chapter 4 Scenario of measures"

*2 The Energy Conservation Center, Japan (2007): Catalog of energy-saving performance 2007 winter

*3 Shiga Prefecture Sustainable Society Research Team, Japan (2005): Report of the study project to create sustainable society in Shiga Prefecture

*4 New Energy and Industrial Technology Development Organization, Japan (2005): Working paper of the field test to introduce high performance industrial furnace

4.8 Parameter estimation in AFOLU sectors

The agricultural land of Bangladesh is very fertile and produces great variety of crops. Crops can be classified into two groups, 1) food crops (rice, wheat, sugarcane and other (maize, potato, vegetables, fruits etc.) and 2) cash crops (jute, tea, cotton and teas etc.). This study considers all types of food and cash crops in Bangladesh. From the year 2000 to 2005 data on harvested area are collected from Ministry of Agriculture, GOB website. Data on 2008 and 2009 harvested area is referred to Statistical Yearbook, 2010 for. Data on 2010 harvested area is estimated by using annual average growth rate of 2009-2010 from FAOSTAT, 2011.

I estimated GHG (CO_2, CH_4 and N_2O) emission and mitigation potentials in the AFOLU sectors from 2005 to 2025 in Bangladesh by using the AFOLU Bottom-up model (AFOLUB, Hasegawa and Matsuoka, 2012). In the period, countermeasures are assumed to be applied after 2010. Two scenarios are assumed:

1) Baseline case without applying mitigation technologies and
2) Countermeasure case with the application of mitigation technologies to reduce the GHG emission

GHG mitigation potential is defined to be a difference of GHG emission between the two scenarios. The main assumptions for Bangladesh in the base year 2005 are shown in Table 4.24.

Table 4.24 The main assumptions for Bangladesh in 2005

Settings	2010	Reference
Population [million people]	164	UN, 2012
Agricultural wage [US$/worker/year]	507	World Bank, 2012
Irrigation area of rice paddy [%]†	40	IRRI, 2011
Wetland of rice paddy [%]†	93	IRRI, 2011
Total nitrogen ferilizer [thousand ton]††	976	MoEF, 2010

† Values are for 2004-2006.

†† Value is for 2001.

4.8.1 Cost

For agriculture sector, i assumed a wide range of emission tax: 0, 10, 100 US$/t$CO_2$eq and over 100 US$/tCO_2eq. For land use change (LULUCF) sector, total mitigation cost from 2010 to 2025 is assumed as 0.1 million US$ to 500 million US$ and the amounts of mitigation costs are averaged out to annual costs. Cost and benefit for land conversion is not taken into account in this study.

4.8.2 Nitrogen fertilizer input

About 60% of the arable land in Bangladesh is deficit in nitrogen (N), phosphorus (P) and potassium (K). Organic matter of soil is much below the critical level of 1.5% (Karim, 1997). Therefore, farmers in Bangladesh normally use urea and it is estimated that 2121096 metric tonne (mt) of urea applied in 2000-2001 (MoEF, 2012), which is the highest among other fertilizers. The total quantity of fertilizer use increases from 3.6 million mt in 2006-07 to 4.1 million mt in 2007-08 fiscal years. Use of artificial fertilizer will be increased in future with the increasing demand of food.

Amount of synthesis nitrogen fertilizer is calculated from area harvested and nitrogen fertilizer per area. The amount of fertilizer is controlled based on the area of cropland. In this study, total nitrogen fertilizer consumption per harvested area and fertilizer input per harvested area by crops in 2001 (MoEF, 2012). This study considers total nitrogen fertilizer of

975704.2 mt in 2001(MoEF, 2012). Table 4.25 shows the amount of nitrogen fertilizer by crops.

Table 4.25 Amount of nitrogen fertilizer by crops

Crops	Nitrogen fertilizer kgN/ha/year
Rice	72
wheat	45
Other coarse grain(maize+barley+other cereal-millet,shorgum)	33
Vegetables(vegetable+fruits+spices+potato)	159
Oil crops (oilseeds)	30
Sugar crops(sugarcane)	85
Other crops(jute+tea+pulses+tobacco+other fibres)	220

4.8.3 Crop yield

For other types of crops yield data on 2010 is calculated from using the annual average change rate from 2000 to 2005, except other coarse grain crop, are assumed as same as 2005. Data from 2000 to 2005, already this crop increases a lot and in the report "World water and food to 2025, Dealing with Scarcity" (Rosegrant et al. 2002), the yield of maize (main crop in this group) is too low. Also oil crops in this study are assumed as same value of crop yield as 2005. Table 4.26 shows the projected crop yield of different crops by 2025.

Table 4.26 Crop yields of different crops

Crops/Year	2000	2005	2010	2015	2020	2025
Rice	2.3	2.5	2.7	2.8	2.9	3.1
wheat	2.2	1.5	1.7	1.9	2.1	2.4
Other coarse grain(maize+barley+other cereal-millet,shorgum)	2.1	5.3	5.7	6.1	6.6	7.1
Vegetables(vegetable+fruits+spices+potato)	6.3	7.0	7.8	8.6	9.6	10.7
Oil crops (oilseeds)	0.9	0.9	0.9	0.9	0.9	0.9
Sugar crops(sugarcane)	39.9	36.2	29.7	24.3	22.1	20.4
Other crops(jute+tea+pulses+tobacco+other fibres)	10.1	11.5	13.1	14.9	16.9	19.2

4.8.4 Share of water management regime

Crop production in Bangladesh predominantly monsoon dependent and this sector is the major water-using for surface and groundwater irrigation being the single most important economic activity in the country. Water demand is increasing rapidly in agriculture, urban and industrial sectors etc. However, irrigation in agriculture is getting higher priority than other sectors as in the dry season the water extraction flow reduces. Due to global warming, rainfall intensity reduces even in the rainy season. About 3 million ha of the total rain fed areas in Bangladesh is estimated to be prone to severe drought. Therefore, farming system recently depends on the irrigation water management regime in Bangladesh. With irrigation covering only around 42% of the potentially irrigated area, agriculture is still weather dependent and has grown slower than is earlier expected, particularly because of the predominantly small farmer holdings in Bangladesh. Table 4.26 shows the water management regime (IRRI, 2011). Therefore, it is a necessity to develop drought tolerant crop varieties and drought mitigating technologies that will make maximum use of the land resources of the rain fed farming systems. Table 4.27 shows the ratio of the water management regime in Bangladesh.

Table 4.27 Share of irrigated and rainfed land in ‘000’hectare

	Total rice cultivated land	Irrigated land	Rainfed land
Area '000' hectare	10797	4319	6478
Percentage	100%	40%	60%

4.8.5 Share of wet-cultivated land and upland

The percentage of the wet cultivated land and upland is referred to Second National Communication (MoEF, 2012). Table 4.28 shows the ratio of the wet cultivated land and upland in Bangladesh.

Table 4.28 Share of wet cultivated and upland in‘000’hectare

	Total rice cultivated land	Wet-cultivated land	Upland
Area '000' hectare	10797	10797	0
Percentage	100%	100%	0%

4.9 Land use sector

Land use changes data from 2005 to 2010 are collected from FAOSTAT, 2011 and Global Forest Resources Assessments, FAO, Country Report, Bangladesh, 2010.

4.9.1 Share of forest classification

The percentage of different forest types in 2005 (production, protection, conservation and other use- social service and multi-use) are shown in Table 4.29

Table 4.29 Share of forest classification

Types of forest	2005
Production forest	31.7%
Protection forest	7.8%
Conservation forest	20.9%
Other use	39.6%

4.10 Livestock sector

Data of livestock number in 2005 and 2008 are collected from the Sixth Five Year Plan of Bangladesh 2011-2015, part 2 (Ministry of Planning, 2011) and the Economic Review, 2009 (General Economic Division, 2009) respectively. In the present study, data in 2009 and 2010 are estimated by using the average annual growth rate from 2005-2010 the report of “Outline Perspective Plan of Bangladesh, Making Vision 2021 A Reality” (Ministry of Planning, 2010) of bovine animals, sheep and goat and poultry.

4.10.1 Feeding system in Bangladesh

Generally, majority of the livestock is maintained in the communal grazing land. They are allowed for grazing during the day time on natural pasture, homestead forest and fallow land. In rural areas a mixture of concentrate like that rice bran, wheat bran and oilcakes are mixed with water is served with straw (M. Saddullah, 2000). Table 4.30 shows the grazing and feeding percentage of livestock.

Table 4.30 Share of the Livestock feeding system

	Percentage	
Livestock type	Grazing	Feeding
Cattle_diary	20%	80%
Cattle_milk	50%	50%
Buffaloes	50%	50%
Sheep	100%	0%
Goats	100%	0%
Camels	100%	0%
Horses	100%	0%
Mules	100%	0%
Asses	100%	0%
Swines	0%	100%
Chickens	0%	100%
Ducks	0%	100%
Turkeys	0%	100%

4.10.2 Annual excretion rate of Nitrogen per animal

The qualitative information on annual nitrogen excretion is collected from Second National Communication, Bangladesh (MoEF, 2012) and used as the input for the model, shown in Table 4.31.

Table 4.31 Annual excretion rate of the livestock

Livestock type	kgN/ animal / year
Cattle_diary	50
Cattle_milk	50
Buffaloes	50
Sheep	12
Goats	12
Camels	36.4
Horses	40.0
Mules	21.8
Asses	21.8
Swines	5.11
Chickens	0.6
Ducks	0.6
Turkeys	0.6

4.11 Assumptions and Settings of Mitigation Technologies

Several mitigation technologies are used in the study for agriculture and LULUCF sectors respectively. The technology information is mainly collected from international and domestic literatures, based on the features of the technology as cost, mitigation effects and agricultural productivity. Therefore, technology selection depends on not only cost and mitigation potential but also the installation of combined technologies to agricultural productivity. Table 4.32 and 4.33 show the detailed information of mitigation technologies in agriculture and LULUCF sectors respectively. Costs of mitigation technologies of the reported country are exchanged into costs of Bangladesh by using wage (World Bank, 2006).

Table 4.32 Mitigation technologies of agriculture and livestock industry

Emission Source	Countermeasures	Code	Cost[USD /(activity・yr)]*	Mitigation[tCO_2 eq/(activity・yr)]*	Reference
Enteric fermentation	Improvement of genetic merit of dairy cows	HGM	0	0.005	Bates(1998)
	Replacement of roughage with concentrated feed	RRC	-23	0.005	Graus et al.(2004),Shibata et al.(2010).
Manure management	Daily spread of manure	DSM	0	0.002	Bates(1998), IPCC(2006)
	Bioenergy from manure	BM	-93	0.17	USEPA(2006)
Rice cultivation	Replace urea with ammonium sulphate	RAS	20	0.31	USEPA(2006), Graus et al. (2004)
	Midseason drainage	MD	0	0.22	USEPA(2006)
	Off-season incorporation of rice straw	OIR	20	0.28	USEPA(2006)
Managed soils	High efficiency fertilizer application	HEF	2	0.24	USEPA(2006), Hendriks et al. (1998), Amann et al. (2005)
	Tillage and residue management	TRM	5	0.34	USEPA(2006), IPCC(2007), Smith et al.(2007)
	Slow-release fertilizer	SRF	700	0.23	USEPA(2006), Akiyama et al.(2010)

*Activity is the area for crop cultivation and animal numbers for livestock

Table 4.33 Mitigation technologies in LULUCF sectors

Mitigation technologies	Code	Cost US$/ha/yr	Mitigation tCO_2eq/ha/yr	Time period (yr)	Reference
Long rotational artificial reforestation	LRR	2.9	10.6	40	Tata Energy Research Institute, 2000
Medium rotational artificial reforestation	MRR	5.5	16.9	20	Tata Energy Research Institute, 2000
Medium rotation sal plantation	MRP	7.4	18.0	20	Tata Energy Research Institute, 2000
Short rotational artificial reforestation	SRR	15.0	12.5	10	Tata Energy Research Institute, 2000
Short rotational participatory woodlot plantation	SRP	11.6	12.5	10	Bangladesh Centre for Advanced Studies, 2000b
Reduced Impact Logging	RIL	0.1	5.1	35	Boer, 2001
Enrichment planting, Enhanced natural regeneration	ENR	0.5	7.3	35	Boer, 2001

Chapter 5 Future assumptions for Energy and AFOLU sectors

The socioeconomic assumptions up to 2025 are described in this chapter. Bangladesh socio-economic development strategies are available in "Outline Perspective Plan of Bangladesh 2010-2021" (Ministry of Planning, 2010) which has a high priority to be used to develop future assumptions. International data sources, such as FAOSTAT (2012), IRRI (2011) and other reports are used in the cases that domestic data is not available. The values of the exogenous variables and coefficients of ExSS and AFOLUB model were determined based on the qualitative information in the plan.

5.1 Setting the cases

This study considered two scenarios, the 2025BaU (business as usual) scenario and 2025CM (countermeasures) scenario. 2005 and 2025 are considered as the base and target year. The amount of GHG emission is projected without reduction measures in 2025BaU and in 2025CM, with reduction measures available for Bangladesh in the year. The parameters related to future energy demand agricultural production and landuse changes, such as energy service demand per driving force, fuel share, energy efficiency, harvested area, livestock number and landuse are changed slightly in 2025BaU. In contrast, in 2025CM reduction measures were introduced in order to estimate the potential reduction of GHG emission from BaU level. The socioeconomic assumptions about population, industry, etc. are common in both cases.

5.2 Socioeconomic projection in energy sector

5.2.1. Demography

Population of Bangladesh in 2025 is taken from "Sectoral Need-based Projections in

Bangladesh" (Bangladesh Bureau of Statistics, 2006). The population will reach 180 million in 2025 from 139 million in 2005. Number of households will rise from 29 million in 2005 to 43 million in 2025. The population composition by sex and age cohort in 2005 and 2025 is shown in Table 5.1.

Table 5.1 Demographic composition by sex and age cohort

Age structure (2005)	Urban	Rural	Total
Age group 0-14	11,493,840	39,322,360	50,816,200
Age group 15-64	21,928,308	61,086,340	83,014,648
Age group 65+	1,197,852	4,731,300	5,929,152
Total	34,620,000	105,140,000	139,760,000
share	25%	75%	100%
Age structure(2025)			
Age group 0-14	17,691,810	25,738,800	43,430,610
Age group 15-64	51,240,180	74,546,400	125,786,580
Age group 65+	4,478,010	6,514,800	10,992,810
Total	73,410,000	106,800,000	180,210,000
Share	41%	59%	100%

5.2.2. Average number of persons per household

This study assumes that persons per household are 4 persons in urban and 4.5 persons in rural household in 2025 (4.9 persons in 2005). In 2025 there will be a significant increase in number of household, with a slight decrease in average number of persons per household and increase of population. The average number of household members and number of households in 2005 and 2025 are shown in Table 5.2 and 5.3 respectively.

Table 5.2 Average number of household members

Household Type	Persons per household in 2005	Persons per household in 2025
Urban	4.9	3.9
Rural	4.9	4.5

Table 5.3 Numbers of households

Household Type	Household numbers in 2005	Household numbers in 2025
Urban	7,130,612	17,505,726
Rural	21,391,837	25,191,167
Total	28,522,449	42,696,894

5.2.3. GDP growth rate

GDP growth rate is assumed 7% in the period of 2005 to 2025BaU. This is an average value of GDP 6% from 2005 to 2010 and 8% by 2015 (Ministry of Planning, 2010). ExSS applies input-output (IO) analysis to project the future industrial structure. In 2025CM, the assumptions will be as same as 2025BaU.

5.2.4. Details of final demand

The distribution of private consumption expenditure share is shown in Table 5.4. It is assumed that the share of consumption of agricultural products decreases and manufactured goods (such as fabricated metal products and machinery, other non-metallic and rubber and plastic product and other chemical products) increases in 2025. Furthermore, the consumption of transport, tourism and hospitality, medical and education and other services increase in 2025. The distribution of export, government consumption expenditure and gross fixed capital formation in 2025 are as same as 2005.

Table 5.4 Distribution of private consumption expenditure

Industry	2005	2025
Agriculture and forestry	10%	5%
Fishing	4%	2%
Minning and Quarrying	3%	4%
Manufacturing	56%	57%
Construction	0%	0%
Electricity, gas & water	2%	3%
Wholesale and retail trade	0%	0%
Transport services	3%	1%
Real estate & renting business	10%	11%
Education and Health	4%	6%
Government services	1%	3%
Other private services	7%	9%
Total	100%	100%

5.2.5. Industry sector

In 2025, GDP will be 14,351 billion taka which results about 3.7 times larger than in 2005. ExSS applies input-output (IO) analysis to project the future industrial structure. Table 5.5 shows changes in demand side of macro-economic indicators.

The industrial sector accounts for biggest contribution to the country’s GDP characterizes by high energy intensity measures such as manufacture materials, metal, paper, etc. Regarding to Government’s ambitious target of industrialization by the year 2021, meeting the national target to be the middle-income country with 2,000US$ per capita income by 2021 (Ministry of Planning, 2010). Energy consumption in this sector is expected to increase in future. Energy service demand per driving force of this sector is assumed to increase at annual 1%. For light industrial sector such as food, beverage and tobacco manufactures, and consumer good etc., I assumed that there is a sharp increasing trend in consuming of electricity and natural gas compare to those of 2005. On the other hand, in heavy industrial sector such as manufacturing and construction etc., coal is expected the primarily energy sources compare to electricity and other sources. In 2025CM case, savings energy consumption is chosen as a low-carbon countermeasure; therefore, we supposed that energy service demand per driving force of industrial sector is as same as BaU per year during the period 2005 to 2025. In this study, energy efficiency for base year (2005) is set to 1 and for target year (2025), assumed the same energy efficiency as the AIM_database due to inefficient information in the country.Table 5.5 shows the future changes in changes in demand side of macro-economic indicators influencing the growth of each industry. GDP (only) is shown in billion taka in table and others indicators' units are in thousand taka.

Table 5.5 Main macro-economic indicators

Indicator	2005	2025	2005/2025
GDP	3,933	14,351	3.6
GDP/capita (thousand taka)	28	80	2.8
Private consumption	3,111	12,028	3.9
Government consumption	204	788	3.9
Fixed capital formation	919	3,554	3.9
Export	756	2,922	3.9
Import	1,057	4,940	4.7

5.2.6. Transport sector

5.2.6.1. Passenger transport

I assumed that passenger transport modal share of road vehicle will be increased due to economic growth and improvement in road sector of the country in 2025BaU. Per capita passenger transport demand is assumed same as base year, 2 trips/capita/day. It is assumed that the private transport mode in road vehicle will be increased due to inefficient and poor public transport development activities of the government in 2025. in passenger transport, is as road vehicle 3% (2% in 2005) due to economic growth and improvement in road sector, railway 0.1% (same as 2005), waterway 0.2% (same as 2005), walk 30% and 38% (49% in 2005) and bicycle 65% and 58% (49% in 2005), increase use of bicycle rather than walking due to reduce travel time in 2025BaU and 2025CM respectively. Railway share increment is considered as reduction measures in 2025CM. Moreover, urban structure is advanced to a compact city, the average trip distances of road vehicle will be shorter than waterway transport in 2025 (Table 5.6). Assumed modal share for 2025 is shown in Table 5.7.

Table 5.6 Average trip distance in 2025 (km)

Mode of Transport	Road vehicle	Railway	Inland water transport	Walk	Bicycle
2005	37.5	132	71.5	2.5	2.5
2025BaU	60	132	71.5	1.6	3.4
2025CM	53	238	71.5	2	3

Table 5.7 Modal share in 2025

Mode of Transport	Road vehicle	Railway	Inland water transport	Walk	Bicycle
2005	0.021	0.001	0.002	0.488	0.488
2025BaU	0.035	0.001	0.002	0.308	0.654
2025CM	0.031	0.002	0.002	0.388	0.578

5.2.6.2. Freight transport

Freight transport demand depends on the industrial output. This study assumed that freight transport modal share of road vehicle will be increased due to increment of modal share of longer travelled distance freight mode in 2025 BaU. In freight transport, modal share is assumed as road vehicle 84% (80% in 2005) due to increment share of longer travelled distance freight mode, railway 4% (same as 2005) and waterway 12% (16% in 2005) in 2025BaU. In 2025CM, the assumptions will be as same as 2025BaU.

Assumed modal share in 2025 is shown in Table 5.8.

Table 5.8 Modal share in 2025

Mode of Transport	Road vehicle	Railway	Inland water transport
2005	0.8	0.04	0.16
2025BaU	0.84	0.04	0.12
2025CM	0.84	0.04	0.12

5.2.7. Estimation procedure of future energy service demand in residential sector

Estimation of the energy consumption by energy service in 2025 needs to consider the trend of change in GDP per capita and energy consumption pattern by residential sector. This study calculated residential energy consumption per household from 2001 and 2006. The growing trend of GDP per capita from 2001 to 2006 (CIA World Factbook, 2011) was considered see Table 5.9. The number of households was calculated by dividing the total population (Bangladesh Bureau of Statistics, 2009) of each year with the average persons of each household which was 4.9 (2001 census). Residential sector energy consumption was taken from energy balance table 2001 and 2006 (IEA, 2003, 2007). The energy consumption per household in residential sector and GDP per capita were calculated. By dividing energy consumption per household with GDP per capita, energy consumption per household per capita GDP was calculated. The energy consumption per household per GDP capita was multiplied by the value of change in GDP per capita growth from 2005 to 2025 of this study (see formula 5.1).

Table 5.9 GDP per capita, energy consumption per household and output in Bangladesh

Year	2000	2001	2005	2006
GDPper capita($ppp)	1570	1750	2100	2300
Energy consumption/household (ton of oil eqv./household no.)		0.349		0.398
Commercial energy consumption ton/output(million taka)	0.046		0.098	

Residential energy consumption (ktoe) per household (number) in 2006 / in 2001 $\div$

GDP per capita in 2006 / in 2001 $\times$ GDP per capita in 2025 / in 2005 =

Increment rate of residential energy consumption per household from 2005 to 2025 (5.1)

(1.142 / 1.314) × 2.830 = 2.459

5.2.8. The calculation of energy service demand per driving force (Esvg)

5.2.8.1 Calculation of residential energy service demand in 2025

In order to estimate Esvg (energy service demand per driving force) of residential sector in 2025, Esvg (except cooking and hot water) in base year (2005) was multiplied by increment rate (see formula 5.1) of energy consumption per household in 2025. The Esvg (except cooking and hot water) was assumed to be increased in 2025. However, the increment rate of final energy demand per household in 2025 became lower than increment rate in formula 5.1. Therefore, Esvg (except cooking and hot water) was assumed a larger value and the Esvg in 2025 (see formula 5.2) was calculated to reach the increment rate of final energy consumption per household (formula 5.1) in 2025.

Esvg in 2005 (residential sector) $\times$ 7.65 = Esvg in 2025 (residential sector) (5.2)

5.2.8.2 Calculation of commercial energy service demand in 2025

In order to estimate Esvg of commercial sector in 2025, formula 5.3 was used to calculate the increment rate of Esvg in 2025.

Commercial energy consumption (ktoe) per output of tertiary industry in 2005 / in 2000 $\div$

GDP per capita in 2005 / in 2000 $\times$ GDP per capita in 2025 / in 2005 =

Increment rate of commercial energy consumption per output from 2005 to 2025 (5.3)

(2.167/ 1.338) × 2.830 = 4.584

Esvg in 2005 (commercial sector) × 4.58 = Esvg in 2025 (commercial sector) (5.4)

However, by using formula 5.4, final energy demand of commercial sector in 2025 showed a big jump from 2005 to 2025, which seemed unreasonable in the context of Bangladesh. Therefore, to estimate Esvg (energy service demand per driving force) of commercial sector in 2025, i applied increment rate of residential sector, and formula 5.5 was used. In this study, energy efficiency for base year (2005) is set to 1 and for target year (2025), assumed the same energy efficiency as the AIM_database due to inefficient information in the country.

Esvg in 2005 (commercial sector) × 2.459 =Esvg in 2025 (commercial sector) (5.5)

5.2.9. Energy composition of national power supply

The energy composition of national electricity supply is shown in Table 5.7, 2005 data was collected from Bangladesh energy balance table 2005 (IEA, 2007). Share of energy mix (coal, oil and hydro) in power generation in 2025BaU is assumed based on the projection of Ministry of Planning (2010). In 2025BaU, share of coal consumption increases significantly to 53% from no use of coal in 2005. The government is going to install two coal-based power plants and will add 2600MW (1300MW of each) to the national supply by 2015. No renewable energy except hydro (1%) is considered as to evaluate possible CO_2 emission in 2025BaU case. In 2025CM, this study introduces nuclear energy and renewables (solar and wind) and reduces share of fossil-fuel. The government has planned to establish a nuclear power plant of 1000MW capacity by 2016 with the technical assistance of Russia. However, in 2025CM share of nuclear energy does not follow projection of Ministry of Planning (2010) of 10% nuclear due to indeterminate future impacts of nuclear power plant. For a country like Bangladesh where the typically installed gas or coal-based power plants are tripping down regularly only due to faulty installation and lack of proper maintenance, how safe will be a sophisticated nuclear power plant is certainly questionable. Therefore, in CM case, this study attempts to reduce nuclear share by half of Ministry of Planning (2010) and increase renewables and hydro share. This study retained the natural gas usage share similar to the BaU case and other fuel share (oil and renewable) followed the share described in Ministry of Planning (2010).

Table 5.10 Energy composition of national power supply

	Coal	Oil	Natural gas	Hydro	Nuclear energy	Renewables (solar and wind)	Total
2005	0%	10%	88%	2%	0%	0%	100%
2025BaU	53%	3%	43%	1%	0%	0%	100%
2025CM	42%	3%	44%	2%	5%	3%	100%

5.3 Future assumption: Agriculture, Livestock and Landuse Change

This section analyses trends and sets future assumptions of agricultural production and land use changes as for input in the AFOLUB model, namely crop harvested area, livestock population and land use changes. I referred domestic data sources for country-specific information such as Ministry of Agriculture (2007, 2012), Ministry of Planning (2010, 2011) etc. International data sources such as FAOSTAT (2012), IRRI (2011) and other reports are also used instead of unavailable domestic data source.

5.3.1 Crop harvested area

This study assumes and projects the crop harvested area up to 2025 for Bangladesh, shown in Fig. 5.1. I have classified all crops into 7 categories; rice, wheat, other coarse grain, oil crops, sugar crops, vegetables and other crops. Crop harvested area data from baseline year 2005 to 2009 are collected from Ministry of Agriculture (2007) and Bangladesh Bureau of Statistics (2010a and 2010b). Crop harvested area is estimated in 2010 by using domestic data for 2009 and annual growth rate of 2009-2010 from FAO (2010b). The proportion of irrigated and rainfed harvested area is estimated as 40% and 60% in 2001 respectively (IRRI, 2011). Data on crop yield from 2005 to 2010 are referred to Ministry of Agriculture (2007) and Rosegrant et al. (2002).

However, the net cropland does not increase so much due to expansion of irrigation facilities, introduction of high-yielding varieties (HYV) crops and high cropping intensity (Ministry of Planning, 2011). In Bangladesh, paddy, the staple crop is cultivated three times in a year with different water regimes (MoEF, 2012). Rice harvested area comprises of 79% and 80% of total cropland area in 2005 and 2010 respectively. The harvested areas under maize, potato, vegetables, pulses, oilseeds and other crops increase significantly from 2005 to 2010. However, wheat and sugar crops show converse trend decreasing by 26% of both categories respectively in 2010 from 2005 level.

This study extrapolates rice production until 2025 by using the annual average growth rate from 2015 to 2021 (MoEF, 2012). Crop harvested area is estimated by dividing the future crop production (ton) by crop yield (ton/ha). All other crop harvested areas are simulated based on the same procedure using the annual average growth rate from 2005 to 2010 of individual crop production. Rice harvested area is expected to increase 1.2 times by 2025 to feed the growing population of the country.

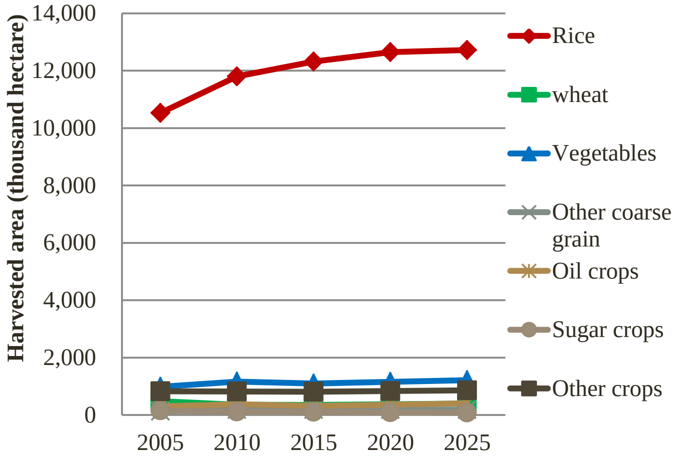


Fig. 5.1 Projected scenario of crop harvested area

5.3.2 Livestock population

Fig. 5.2 shows the future livestock population until 2025. In this study, livestock population includes cattle, buffalo, sheep and goat and poultry (chicken and duck). Data on livestock number from 2005 to 2010 are collected from Ministry of Finance (2011) and Ministry of Planning (2011). The ratio of milk and beef cattle to disaggregate total cattle population is referred to FAO (2011b) and the ratio will be constant for future years. Cattle number increases from 23 million in 2005 to 24 million in 2010, having 60% of milk cattle in total cattle population in Bangladesh. Sheep and goat number increase to 3 and 23 million or 12% and 13% of increase in number in 2010 from 2005 level. Poultry number increases sharply with 15% of increase in number in 2010 from in 2005.

Ministry of Planning (2010) is referred to project future livestock population based on annual average growth rate from 2015 to 2021and projected livestock number for the years of 2015, 2020 and 2025 respectively. Cattle population increases to 28 million in 2025 from 24 million in 2010. In addition, goat number significantly increases to 28 million in 2025 from 2010. For poultry, chicken and duck number increases to 271 million and 51 million in 2025 from 226 and 42 million in 2010 respectively.

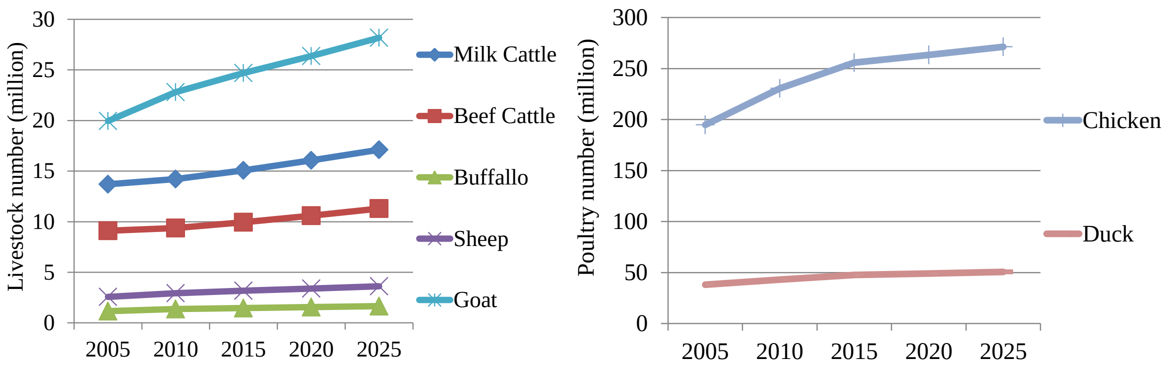


Fig. 5.2 Projected scenario of livestock and poultry number

5.3.3 Land Use Change

This study projects land use changes by 2025 based on the historical trend, shown in Fig. 5.3. In Bangladesh, net forest land area is shrinking due to rapid population growth, urbanization rate and economic development to meet the increasing needs for cooking fuel. Natural forest areas constitute almost 31% and forest plantation 13% of forest areas in Bangladesh (Bangladesh Centre for Advanced Studies, 2000a).

Land use changes data from 2005 to 2010 are collected from FAO (2010b and 2011b). According to the historical trend, forest land decreases from 1.5 million hectares to 1.4 million hectares in this period. The cropland area in Bangladesh covers 60% and 59% of total land area in 2005 and 2010 respectively. Other land increases to 2.5 million hectares, resulting 9% increase in 2010 from 2005 level.

This study uses annual average growth rate from 2005 to 2010 to project cropland in 2020 and 2025. Forest land in 2015 is projected by using annual average growth rate from 2005 to 2010. In 2020, production forest increases by 20% as reported in Ministry of Planning (2010) that rises 20% of productive forest cover by 2021. Other types of forestland are increased by using annual average growth rate of 2005-2010 until 2020. In 2025, projection uses annual average growth rate of 2000-2005 to make pace with qualitative information gathered from different literatures. Forest land will be almost similar in 2025 as 2020 with slight decrease of 2% of area from 2010. Other land area is defined as built up (urban and rural settlements, highways and others) area and increases significantly to 19% in 2025 from 17% in 2010 to meet the growing demand of settlement. This study considers constant growth of grass land and inland water land without taking into account natural disaster and forest fire.

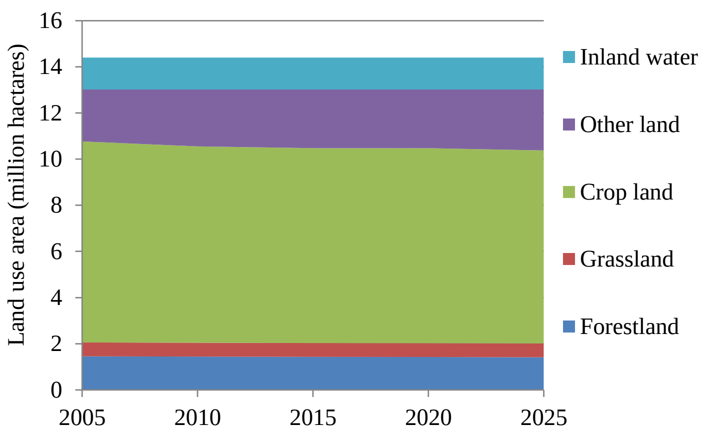


Fig. 5.3 Projected scenario of land use changes

Chapter 6 Results and discussion

Quantified socio-economic activity level, energy demand, crop harvested area, livestock number and landuse change by 2025 in Bangladesh are discussed in this chapter.

6.1 Socio-economic projection

The estimated results of socio-economic projection are shown in this chapter. ExSS estimates socio-economic activity level for Bangladesh in 2025. The population and GDP will be increased 1.3 times and 3.5 times from 2025BaU than in 2005 respectively. Freight transport demand will be increased about 4.5 times with the increment of modal share of road vehicle which has the longer trip distance than other mode in 2025BaU. The estimated results of the main socioeconomic indicators are shown in Table 6.1.

Table 6.1 Estimated results of the main socioeconomic indicators

Parameter	2005	2025BaU	2025CM	2025BaU/2005	2025CM/2005
Population (million)	140	180	180	1.3	1.3
No. of households (million)	29	43	43	1.5	1.5
GDP (billion Taka)	3933	14351	14351	3.6	3.6
Gross output (billion Taka)	8932	32279	32279	3.6	3.6
Primary industry (billion Taka)	1864	4971	4971	2.7	2.7
Secondary industry (billion Taka)	4032	15493	15493	3.8	3.8
Tertiary industry (billion Taka)	3035	11815	11815	3.9	3.9
Passenger transport demand (billion pass-km)	361	663	617	1.8	1.7
Freight transport demand (billion tonne-km)	20	91	91	4.5	4.5

The passenger transport demand in Bangladesh will be increased about 1.8 times from 361 billion passenger-km in 2005 to 663 billion passenger-km in 2025BaU (Table 6.2). In 2025CM, transport volume will be slightly decreased to 617 billion passenger-km by adopting some reduction measures. In 2025BaU, this study assumes that passenger transport modal share of vehicle and bicycle will be increased while share of walk is reduced. Private transport mode in road vehicle will be increased due to income growth and shortfall of public transport development. However, urban structure is assumed to be more compact than 2005, the average trip distances of road vehicle will be shorter than other transport in 2025BaU. In 2025CM, under reduction measures, modal shift to railway was introduced. In addition, pedestrian road for walk and bicycle can be recommended as potential measure to reduce traffic jam and provide people a convenient and safe transport. Thus, 2025CM assumed modal share of walk will also be increased from BaU.

Freight transport demand is also increased from 20 billion ton-km (2005) to 91 billion ton-km in 2025BaU because of growth of industries (Table 6.3). In 2025BaU, freight transport demand will be increased about 4.5 times larger than in 2005. The transport demand depends on the industrial output which is 3.6 times (2025) larger than in 2005. Transport demand will be increased more than increase of output of industry because modal share of the road vehicles increased rather than freight waterway and railway for freight transport which will have the longer distance than other mode.

Table 6.2 Passenger transport volume (million pass-km)

Transport mode	Transport volume in 2005	Transport volume in 2025BaU	Transport volume in 2025CM	2025BaU/2005	2025CM/2005	2025CM/2025BaU
Railways	13	17	56	1.3	4.2	3.2
Waterway	15	19	19	1.3	1.3	1.0
Road vehicle	84	275	215	3.3	2.6	0.8
Walk	124	64	101	0.5	0.8	1.6
Bicycle	124	288	225	2.3	1.8	0.8
Total	361	663	617	8.7	10.7	7.4

Table 6.3 Freight transport volume (million ton-km)

Transport mode	Transport volume in 2005	Transport volume in 2025BaU	Transport volume in 2025CM	2025BaU/ 2005	2015CM/ 2005	2025CM/ 2025BaU
Railways	0.5	2	2	4	4	1
Road vehicle	17	83	83	5	5	1
Waterway	3	6	6	2	2	1
Total	20	91	91	11	11	3

The output by industries is shown in Table 6.4.

Table 6.4 Output by industries

Industry	Output (million Taka)		Ratio	Composition percentage	
	2005	2025	2025/2005	2005	2025
Agriculture and forestry	1,459,345	3,682,115	2.5	16%	11%
Fishing	404,887	1,288,968	3.2	5%	4%
Minning and Quarrying	202,902	793,939	3.9	2%	2%
Manufacturing	3,042,402	11,622,418	3.8	34%	36%
Construction	656,219	2,518,588	3.8	7%	8%
Electricity, gas & water	130,725	557,793	4.3	1%	2%
Wholesale and retail trade	701,368	2,430,956	3.5	8%	8%
Transport services	641,479	2,066,043	3.2	7%	6%
Real estate & renting business	492,430	1,974,391	4.0	6%	6%
Education and Health	239,115	1,129,031	4.7	3%	3%
Government services	167,560	913,085	5.4	2%	3%
Other private services	793,145	3,301,916	4.2	9%	10%
Total	8,931,578	32,279,245	3.6	100%	100%

Table 6.4 shows output from industries. The share of primary industry output (agriculture and forestry, fishing) will be decreased from 21% (2005) to 15% in 2025. Share of secondary industry (mining and quarrying, manufacturing and commercial goods, construction and electricity, water and gas) will be increased from 45% (2005) to 48% and tertiary industry

(Wholesale and retail trade, transport services, real state and renting business, education and health, government services and other private services) from 34% (2005) to 37% in 2025.

6.2 Energy demand

6.2.1. Reasons of energy demand expansion

Rising energy demand is driven by urbanization and industrialization in Bangladesh. Analyzing growth trends in previous years, i can summarize the reasons of current energy demand expansion which will lead to the future demand expansion, as

- Economic growth performance improves with sequential increase in GDP growth rate from 6.1% in 2009 to 6.7% in 2011 (CPD, 2012).
- The life style of citizen advances with rapid urbanization which increases energy consumption per capita to 209kgoe in 2010 from 159kgoe in 2003 (World Bank, 2013).
- Electricity access increases to 60% in 2012 (including renewable sources) from 38% in 2005 due to generation capacity rise through establishment of new oil based infrastructure of quick rental power plant (QRPP) with 10% of additional distribution line in 2012 from 2005 and over 1.88 million household-level installations having capacity of about 80 MW in 2012 provided by Infrastructure Development Company Limited (IDCOL) (Energypedia, 2013 and Mondal et al., 2012).
- 33% of electricity consumption is increased in 2010 from 2004 with reduction of transmission and distribution loss to 18% in 2010 from 21% in 2005 (Ministry of Planning, 2011).
- Industrial production growth rate (the annual percentage increase in industrial production) increases to 7.4% in 2011 from 6.2% in 2001, focuses manufacturing, mining, and construction (World Bank, 2012).

6.2.2. Final energy demand

In demand side, largest share of energy is consumed by residential sector of about 68% total 16.8 Mtoe in 2005, which will be increased to 63Mtoe in 2025BaU (Fig. 6.1) (Tahsin et al., 2012). As a solo consumer of biomass, this sector shows 45% increase in consumption in 2025BaU. Due to the increased demand of transport, energy demand of transport sectors also increased significantly. Passenger transport demand and freight transport demand will increase to 1.8 times and 4.5 times due to rapid transport growth, resulting 2.8 and 4.2 times higher petroleum demand in 2025BaU respectively. Energy consumption of industrial sector is 3.7Mtoe of the total final energy demand in 2005 and increases 3.5 times in BaU case due to the increment of industrial production. Natural gas consumption in this sector increase 73% in 2025BaU from 2005.

In 2025CM, energy demand will reduce to 48Mtoe from 63Mtoe in 2025BaU. Share of residential sector will be 66%, same as 2025BaU. Industry will consume 24%, transport sector 6% and commercial sector 4% of the total energy demand in 2025CM.

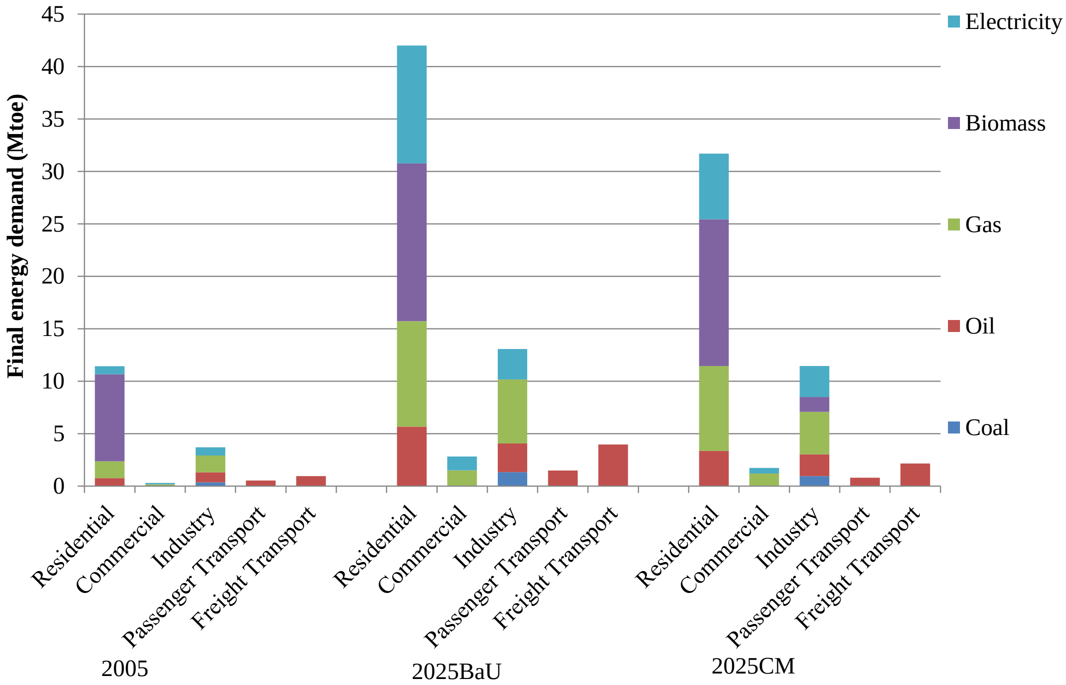


Fig. 6.1 Estimated results of final energy demand

6.2.3. Energy demand by residential and commercial sector

Table 6.5 and 6.6 shows the final energy demand in residential and commercial sector in 2005, 2025BaU and 2025CM respectively.

Residential sector is the solo consumer of biomass for domestic cooking of 72% of country's energy supply in 2005. About 72% of urban and 99% of rural households depend on traditional biomass energy and only 4% of urban households have access to natural gas network for cooking purpose in the country in 2005 (Munim et al. 2010). Munim et al. (2010) report, oil (kerosene) is used by 37% of urban and 91% of rural households for lighting. Natural gas demand will increase to 10049ktoe or 84% larger in 2025BaU than in 2005. It is assumed that energy demand (electricity) will grow more 14.6 times in BaU case as priority basis to satisfy the national target of 100% electrification by 2021 and to satisfy other energy service demand. Hot water heating (parboiling for rice mills) consumes 24% of more energy, mainly biomass in 2025BaU. Getting more urbanized, people will consume 3.7 times more energy in 2025BaU using various electric devices (television, computer, iron) to upgrade living standard. Applying reduction measures such as energy efficiency improvement of electrical equipment can reduce 25% of energy demand in 2025CM. In 2025CM energy demand will be reduced to 42013ktoe in which electricity contributes 44% of emission reduction.

Table 6.5 Final energy demand in residential sector (ktoe)

	Coal	Oil	Gas	Biomass	Electricity	Total
2005	0	750	1,616	8,296	768	11,430
2025BaU	0	5,665	10,049	15,043	11,256	42,013
2025CM	0	3,350	8,097	13,996	6,261	31,704
Share Base	0	7%	14%	73%	7%	100%
Share BaU	0	13%	24%	36%	27%	100%
Share CM	0	11%	26%	44%	20%	100%

Energy demand in commercial sector is driven by the growth of service sector, which growth will be 3.9 times larger in 2025 than in 2005. Commercial sector consumes 2,822ktoe in 2025BaU of which heating and cooking (water heating and cooking in hospitals and hotels and restaurants) comprising of 990ktoe and 632ktoe of energy demand respectively. In 2025CM, improvement in energy efficiency (electric devices, insulation of buildings), efficiency improvement in power sector will contribute 38% of energy demand reduction in this sector.

Table 6.6 Final energy demand in commercial sector (ktoe)

	Coal	Oil	Gas	Biomass	Electricity	Total
2005	0	0	159	0	138	297
2025BaU	0	0	1509	0	1313	2822
2025CM	0	0	1187	0	550	1737
Share Base	0	0	54%	0	46%	100%
Share BaU	0	0	53%	0	47%	100%
Share CM	0	0	68%	0	32%	100%

6.2.4. Energy consumption by industries

Table 6.7 shows the energy demand by industry in 2005, 2025BaU and 2025CM respectively. Industry sector in this study comprises of primary and secondary industries. The outputs of these industries increase to 20,464 billion taka in 2025 at GDP growth rate of 7%, which is 3.5 times larger than 5,897 billion taka in 2005. Energy demand in industrial sector will increase to 13,068ktoe in 2025BaU from 3,700ktoe in 2005. In 2025CM, by adopting measures e.g. energy efficiency improvements energy demand will be decreased to 11,443ktoe. Furnace contributes the highest reduction of 66% in energy demand followed by steam boiler contribution of 30% in 2025CM.

Table 6.7 Final energy demand by industry sector (ktoe)

Industry	Coal	Oil	Gas	Biomass	Electricity	Total
2005						
Agriculture and forestry		674	58	0	44	776
Fishing		46	37	0	28	111
Minning and Quarrying	1	2	5	0	2	10
Manufacturing	340	218	1,435	0	665	2,658
Construction	9	9	76	0	35	130
Electricity, gas & water	0	2	9	0	4	15
Total	350	950	1,621	0	779	3,700
2025Bau						
Agriculture and forestry	0	1,701	146	0	111	1,958
Fishing	0	146	118	0	90	354
Minning and Quarrying	3	7	20	0	9	39
Manufacturing	1,298	832	5,483	0	2,540	10,154
Construction	36	33	293	0	136	497
Electricity, gas & water	0	8	40	0	18	66
Total	1,337	2,727	6,100	0	2,904	13,068
2025CM						
Agriculture and forestry	0	1,224	363	0	181	1,767
Fishing	0	96	107	0	93	296
Minning and Quarrying	4	5	16	0	8	33
Manufacturing	910	731	3,279	1,407	2,548	8,876
Construction	24	32	242	0	116	415
Electricity, gas & water	0	8	33	0	15	55
Total	938	2,097	4,040	1,407	2,960	11,443

6.2.5. Energy consumption by transport sector

Table 6.8 shows the energy demand by transport sector in 2005, 2025BaU and 2025CM respectively. In transport sector, numbers of vehicles increase with population growth and migration from rural to urban area induces the increase in energy demand of 76% of road vehicle in 2025BaU. In 2025BaU, total energy demand will be increased to 5,441ktoe or 3.7 times larger than in 2005. Energy efficiency improvement of road vehicles and modal shift reduces 46% of energy demand in 2025CM. This study excludes fuel switch measure from oil to natural gas (Compressed Natural Gas, CNG) due to minimize the growing pressure on natural gas reserves in Bangladesh.

Table 6.8 Final energy demand by transport sector (ktoe)

	Transport Mode	Coal	Oil	Gas	Biomass	Electricity
Passenger transport	Road vehicle	0	404	0	0	0
	Railway	0	21	0	0	0
	Inland water transport	0	105	0	0	0
Freight transport	Road vehicle	0	646	0	0	0
	Railway	0	84	0	0	0
	Inland water transport	0	210	0	0	0
2025BaU						
Passenger transport	Road vehicle	0	1,320	0	0	0
	Railway	0	27	0	0	0
	Inland water transport	0	135	0	0	0
Freight transport	Road vehicle	0	3,094	0	0	0
	Railway	0	354	0	0	0
	Inland water transport	0	510	0	0	0
2025CM						
Passenger transport	Road vehicle	0	647	0	0	0
	Railway	0	88	0	0	0
	Inland water transport	0	68	0	0	0
Freight transport	Road vehicle	0	1,547	0	0	0
	Railway	0	354	0	0	0
	Inland water transport	0	255	0	0	0

6.2.6. Primary energy demand by energy type

ExSS estimated primary energy demand by energy type in 2025BaU and 2025CM (Table 6.9). Projected result shows that total primary energy demand increases to 95413ktoe in 2025BaU from 20539ktoe in 2005, 4.6 times larger than in 2005. By adopting reduction measures, energy demand will be decreased to 63696ktoe in 2025CM from 2025BaU. In 2005, dominating primary energy source is biomass which covers about 40% of total energy demand and the second is natural gas. This structure will be changed in 2025BaU. Coal consumption increases from 2% in 2005 to about 28% in 2025BaU, which are mainly consumed by power and industrial sector. This study shows the reduction of share of traditional biomass from 40% (2005) to 16% in 2025BaU. However, using low-carbon savings measures, significant decrease in coal consumption of 18% is shown in 2025CM from 202BaU.

Table 6.9 Estimated results of primary energy demand (ktoe)

	Coal	Petroleum	Gas	Hydro	Nuclear	Solar/ wind	Biomass	Total
Energy demand								
2005	350	3,704	8,078	111	0	0	8,296	20,539
2025BaU	26,420	15,070	38,231	648	0	0	15,043	95,413
2025CM	11,751	9,178	24,667	513	1,310	873	15,403	63,696
Percentage distribution								
2005	2%	18%	39%	1%	0%	0%	40%	100%
2025BaU	28%	16%	40%	1%	0%	0%	16%	100%
2025CM	18%	14%	39%	1%	2%	1%	24%	100%

6.2.7. Energy demand in power sector

This study estimated that per capita electricity consumption was 162 kWh/person/year in 2005, 1129 kWh/person/year in 2025BaU and 705 kWh/person/year in 2025CM. Energy demand by fuel in power sector is shown in Table 6.10. Natural gas provides more than two-third of country's commercial energy supply (Munim et al., 2010), of which 88% of energy is used for power generation. However, Bangladesh has potential amount of coal reserves to meet the government's target in power sector, coal will be the possible fuel instead of natural gas for electricity generation in future. Table 8 shows the growing usage of coal in 2025BaU to meet the target of the government that ensures electricity for all by 2021 (Ministry of planning, 2010). In 2025BaU, share of coal consumption will be increased drastically to 25Mtoe and only hydro is considered as renewable energy for power generation. Natural gas increases to 21Mtoe or 77% more in 2025BaU than in 2005. The model estimates 46% of energy demand reduction by applying reduction measures as reduce transmission and distribution loss.

Table 6.10 Energy demand by fuel in power sector (ktoe)

	Coal	Oil	Gas	Hydro	Nuclear	Renewables	Total
2005	0	534	4,682	111	0	0	5,327
2025BaU	25,082	1,238	20,573	648	0	0	27,963
2025CM	10,813	773	11,342	513	1,310	873	16,056
2005	0%	10%	88%	2%	0%	0%	100%
2025BaU	53%	3%	43%	1%	0%	0%	100%
2025CM	42%	3%	44%	2%	5%	3%	100%

6.3 CO_2 emission from energy sector

The estimated result of CO_2 emission is shown in Table 6.11. CO_2 emission increased 7.6 times in 2025BaU and 4.2 times in 2025CM from 2005. Per capita CO_2 emission increased to 1.34 tCO_2-eq in 2025BaU from 0.23 tCO_2-eq in 2005. In 2025CM per capita CO_2 emission decreased to 0.74 tCO_2-eq from 2025BaU. Therefore, per capita emission in 2025CM is reduced by 45% from BaU.

In 2025BaU, the main contributor of CO_2 emission is residential and emits about 63% of total emission. Industrial sector, commercial sector and transport sector cover 23%, 7% and 7% respectively. In 2025BaU, CO_2 emission increases more than GDP growth rate. The reasons are as follow: 1) in residential sector, biomass share is reduced and other fuels especially gas and coal (power sector) is increased. Therefore, even though the final energy demand is increased by only 3.7 times, CO_2 emission is increased more about 12.6 times. 2) In power supply sector, coal increases its share (0% to 53%) while natural gas is reduced from 88% to 43%. In 2025CM, potential of emission reduction is about 45% of 2025BaU through introducing efficient measures in 2025CM. As a result, CO_2 emission factor of electricity increased significantly (from 2.04 to 2.67tC/toe).

Table 6.11 CO_2 emission ($MtCO_2$-eq)

Sectors	2005	2025 BaU	2025 CM	BaU/CM	CM/Base
Residential sector	12	151	75	12.8	6.4
Commercial sector	1	16	7	11.6	4.9
Industrial sector	14	56	41	4.0	3.0
Passenger transport sector	2	5	2	2.8	1.5
Freight transport sector	3	12	7	4.2	2.3
Total	32	241	133	7.6	4.2

6.4 Emission reduction towards LCS in Bangladesh

The CO_2 emission in Bangladesh was 31.7 $MtCO_2$-eq in 2005. In 2025BaU, CO_2 emission increased to 240.7 $MtCO_2$-eq. However in 2025CM, the CO_2 emission reduced to 132.6 $MtCO_2$-eq by adopting reduction measures (Fig. 6.2). In 2025BaU, residential sector was the largest CO_2 emission sector and the emission about 63% of total. The next is industrial sector 23%, commercial sector 7% and transport sector 7%. The largest reduction of 70.8 $MtCO_2$-eq can be achieved by improving energy efficiency, where residential and commercial sectors accounted 58.6 $MtCO_2$-eq, industrial sector 5.1 $MtCO_2$-eq and transport sector (passenger and freight) 7.1 $MtCO_2$-eq. The second largest reduction can be achieved by power supply (reducing transmission loss and fuel switch to renewables and nuclear) which contributed about 30.9 $MtCO_2$-eq.

A sum of fuel switch (from oil to gas) in all demand sectors also contributed 5.8 $MtCO_2$-eq where major share was covered by residential, commercial and industrial sector by 5%. Table 6.12 shows the CO_2 emission reduction by sector by category of measures.

Some countermeasures for CO_2 emission reduction by sectors are following:

- **Residential and commercial sector;**

- Energy efficient lighting (compact fluorescent lights, CFL from incandescent bulb) and electric fan.
- Efficient cooking system (improved cooking stove, using metered gas and solar power).

- Efficient refrigeration.
- Efficient cooling system.

- **Industrial sector;**

- Energy efficient direct heating system, steam boiler and motor.
- Fuel switch from oil to natural gas.

- **Transport sector;**

- Energy efficiency improvement in old and reconditioned engines of road vehicles.
- Modal shift from private vehicle to public transport and railway.

- **Power sector;**

- Fuel switch.
- Reduction of transmission loss

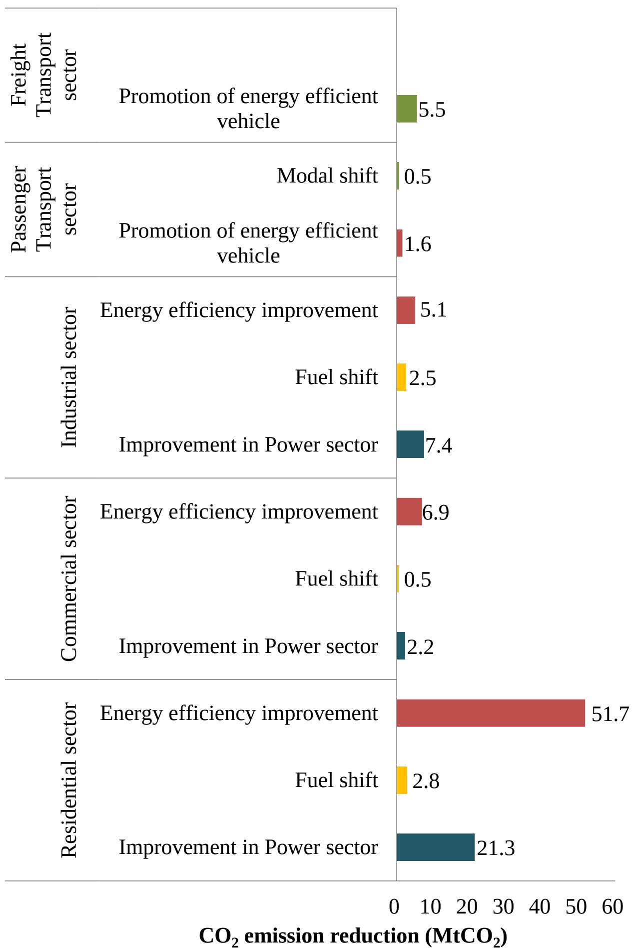


Fig. 6.2 CO_2 emission reduction by sectors by category of measures

Table 6.12 CO_2 emission reduction by sectors ($MtCO_2$-eq)

	Improve efficiency of power supply	Fuel switch	Improve energy efficiency	Modal shift	Total
Residential sector	21	3	52	0	76
Commercial sector	2	0	7	0	10
Industrial sector	7	3	5	0	15
Passenger Transpor	0	0	2	1	2
Freight Transport	0	0	6	0	6
Total	31	6	71	1	108

6.5 CO_2 emission reduction by sectors

6.5.1. CO_2 emission reduction in residential sector

The increment of energy demand in the residential sector depends on the population growth, number of households and GDP. Population will be increased to 180 million from 139 million (2005) and number of household to 43 million in 2025 from 28 million (2005) of Bangladesh. Energy demand in residential sector will be increased to 42,013ktoe which was about 3.7 times larger in 2025BaU than in 2005. CO_2 emission will be increased to 151.2 $MtCO_2$-eq that is 12.8 times larger in 2025BaU than in 2005. About 75.8 $MtCO_2$-eq of CO_2 emission reduction can be achieved by adopting reduction measures e.g. energy efficiency improvement of electrical, fuel switch and non-electrical equipment and improvement in sector (it reduces emission from electricity generation which is consumed by residential sector). Efficient lighting, refrigerator and cooling options were the most potential and covered 53 $MtCO_2$-eq or 71% of reduction of CO_2 emission in this sector.

6.5.2. CO_2 emission reduction in commercial sector:

Energy demand in commercial sector is driven by growth of tertiary industry output. In 2025BaU, the output of the tertiary industry will be increased 3.9 times larger than in 2005 and energy demand increased to 2,822ktoe and CO_2 emission 16 $MtCO_2$-eq, which is about

9.5 and 11.6 times greater than 2005. In 2025CM, reduction measures e.g. improvement in energy efficiency (electric devices, insulation of buildings), efficiency improvement in power sector and fuel switch were the potential options for CO_2 emission reduction, reduces about 9.6 $MtCO_2$-eq contributed about 9% of the total emission reduction.

6.5.3. CO_2 emission reduction in industries

"Industrial sector" in this study comprises primary and secondary industries. This report assumed that GDP growth rate will be 7% by 2025. The outputs of the industries increased to 20,464 billion taka in 2025, which was 3.5 times larger than 5,897 billion taka in 2005. Energy demand in industrial sector increased to 13,068 ktoe in 2025 from 3,700ktoe in 2005 (Table 6.13). Without adopting any low-carbon measure in 2025BaU; the CO_2 emission will be increased to 56 $MtCO_2$-eq, about 4 times larger than in 2005. In 2025CM, by adopting reduction measures e.g. energy efficiency improvements and fuel switch, CO_2 emission will be decreased to 41 $MtCO_2$-eq.

Table 6.13 Energy demand by services by energy type in industry

2005Base	Coal	Oil	Gas	Biomass	Electricity	Total
Furnace	172	123	616	0	70	981
Boiler	144	447	794	0	0	1,384
Motor	0	4	0	0	608	612
Others	35	376	210	0	101	723
Total	350	950	1,621	0	779	3,700
Share	9%	26%	44%	0%	21%	100%
2025BaU						
Furnace	655	354	2,318	0	261	3,589
Boiler	548	1,282	2,989	0	0	4,819
Motor		12	1	0	2,265	2,278
Others	134	1,079	792	0	378	2,382
Total	1,337	2,727	6,100	0	2,904	13,068
Share	10%	21%	47%	0%	22%	100%
2025CM						
Furnace	459	195	1,234	342	281	2,512
Boiler	340	1,015	1,996	975	11	3
Motor	0	0	0	0	2,212	2,212
Others	139	887	810	90	456	2,382
Total	938	2,097	4,040	1,407	2,960	11,443
Share	8%	18%	35%	12%	26%	100%

6.5.4. CO_2 emission reduction in power supply

In this study, 2025BaU followed the projected composition of energy mix in existing planning, (Ministry of Planning, 2010) without applying any renewable energy except hydro power, and CO_2 emission was estimated. On the other hand, in 2025CM, reduction measures e.g. reduction of transmission loss and fuel switch from non-renewable to renewable energy (solar, hydro, nuclear energy) reduced the emissions by 303 $MtCO_2$-eq and contributed about 29% of total CO_2 emission reduction. In 2025CM, this study introduced nuclear energy and renewables (solar, wind), reducing the share of coal for potential CO_2 emission reduction. The composition of low carbon energy mix for power generation in 2025CM is shown in Table 6.14.

Table 6.14 Power supply indicators (ktoe)

2005	Coal	Oil	Gas	Hydro	Nuclear	Solar&Wind	Total
Fuel input	0	534	4,682	111	0	0	5,327
Generation	0	131	1,705	111	0	0	1,947
Own-use(5.2%)	0	7	89	6	0	0	101
Transmission-loss(8.2%)	0	11	140	9	0	0	160
Final consumption	0	114	1,476	96	0	0	1,686
Share	0%	10%	88%	2%	0%	0%	100%
2025BaU							
Fuel input	25,082	1,238	20,573	648	0	0	47,542
Generation	9,046	304	7,490	649	0	0	17,489
Own-use(5.2%)	470	16	389	34	0	0	908
Transmission-loss(6.3%)	573	19	475	41	0	0	1,108
Final consumption	8,003	269	6,627	574	0	0	15,473
Share	53%	3%	43%	1%	0%	0%	100%
2025CM							
Fuel input	10,813	773	11,342	513	1,310	873	25,625
Generation	3,900	190	4,129	514	1,310	873	10,917
Own-use(5.2%)	203	10	214	27	68	45	567
Transmission-loss(5.3%)	206	10	219	27	69	46	578
Final consumption	3,491	170	3,696	460	1,173	782	9,772
Share	42%	3%	44%	2%	5%	3%	100%

6.5.5. CO_2 emission reduction for sustainable transport

In 2025BaU the energy demand will be increased from 530 to 1,483 ktoe or 2.8 times larger than 2005. The CO_2 emission from passenger transport will be increased to 4.6 $MtCO_2$-eq in 2025BaU from 1.6 $MtCO_2$-eq in 2005. However, in 2025CM by adopting possible reduction measures e.g. energy efficiency improvement and modal shift; emission will be reduced to 2.1 $MtCO_2$-eq which contributed about 1% and 0.5% of total CO_2 emission reduction respectively. This study excluded fuel switch measure from oil to natural gas (Compressed Natural Gas, CNG) due to minimize the growing pressure on natural gas reserves, which can meet national demand until 2016 (Ministry of Energy, Power and Mineral Resources, 2010) in Bangladesh. In freight transport sector, freight transport volume will be increased from 20 billion ton-km in 2005 to 91 billion ton-km in 2025. Energy demand and CO_2 emission in freight transport will be increased to 3,958 ktoe and 12.2 $MtCO_2$-eq in 2025BaU. In 2025CM, energy efficiency improvement contributed about 5.5 $MtCO_2$-eq reduction or 5% of the total emission reduction.

6.5.6. Summary of reduction measures towards CO_2 emission reduction

For Bangladesh, building a LCS will be both a challenge and an opportunity. The concept of LCS is not only to reduce GHG emission, but also focuses on better energy efficiency which then may improves economic productivity and energy security. This study projected CO_2 emission can be reduced about 45% in 2025CM by adopting some effective and feasible reduction measures.

Brief overviews of possible reduction measures and emission reductions are shown in Table 6.15.

Table 6.15 Summary of CO_2 emission reduction from proposed measures in energy sector

Reduction measures	CO_2 emission reduction ($MtCO_2eq$)	(%)
1. Energy efficiency improvement in residential and commercial sector	59	54%
2. Energy efficiency improvement in industrial sector	5	5%
3. Fuel switch in residential, commercial and industrial sector	6	5%
4. Promotion of energy efficient vehicles (passenger+freight transport)	7	7%
5. Modal shift in passenger transport sector	1	0.5%
6. Fuel switch and reduction of transmission loss in power sector	31	29%
Total CO_2 emission reduction ($MtCO_2eq$)	108	100%
Total CO_2 emission ($MtCO_{2\text{-}eq}$) in 2025BaU	241	
Total CO_2 emission ($MtCO_{2\text{-}eq}$) in 2025CM	133	

Fig. 6.3 shows the sectors contribution in CO_2 emission reduction. Residential sector is the main contributor of 50% emission reduction by adopting reduction measures e.g. energy efficiency improvement and fuel shift in the emission reduction. Power sector is positioned as second and achieved 29% of emission reduction by adopting the improvement in power sector (it reduces the emission from electricity generation which is consumed by different sectors). Commercial, industrial, passenger transport and freight transport sector contribute 7%, 7%, 2% and 5% in emission reduction respectively.

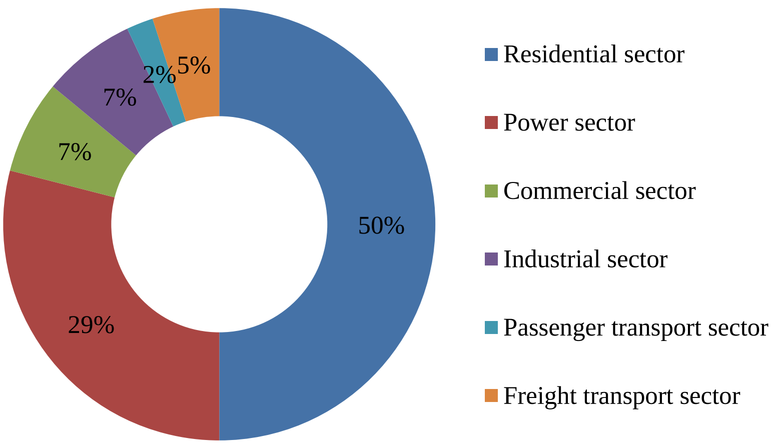


Fig. 6.3 Sectors contribution in CO_2 emission reduction

6.6 GHG emission from AFOLU sectors

Total GHG emission from agriculture and LULUCF sectors is expected to increase 1.2 times larger in 2025 than in 2005. Fig. 6.4 shows GHG (CH_4 and N_2O) emission from agriculture sector from 2005 to 2025. In 2025, total GHG emission from agriculture sector will increase 1.3 times or 24% more than total GHG emission in 2005. Enteric fermentation in livestock is the largest contributor of 29% of total GHG emission from agriculture in 2005. Manure management generates the larger amount of emission in agriculture 6.4 $MtCO_2$-eq of CH_4 and 11.4 $MtCO_2$-eq of N_2O in 2005 and will increase to 8.2 $MtCO_2$-eq and 14.8 $MtCO_2$-eq in 2025 respectively. The share of irrigated rice cultivation is only 40% from 2004 to 2006, emits 8.7 $MtCO_2$-eq of CH_4 in 2025, which is 15% of the total emission and 1.2 times larger than emission in 2005. Manure management (livestock dung and urine) contributes N_2O of 11.4 $MtCO_2$-eq in 2005, which shares 65% of the total N_2O emission in this sector. Application of nitrogen fertilizer in the context of managed soil increases to 9.6 $MtCO_2$-eq in 2025 from 6.1 $MtCO_2$-eq in 2005. The GHG emission gradually increases to 47 $MtCO_2$-eq in 2010 from 42.9 $MtCO_2$-eq in 2005. It is assumed that increment trend will be continued up to 2025. 37% of N_2O emission will be increased by 2025 compared to the emission in 2005 due to increased dependency on the utilization of artificial fertilizer (mainly nitrogenous) to manage soil fertility and increment of crop yield. Moreover, due to sharp increase in livestock population, emission from livestock manure management is expected to increase to 14.8 $MtCO_2$-eq of N_2O emission in 2025 from 11.4 $MtCO_2$-eq in 2005. Livestock enteric fermentation and manure management account for 15.2 $MtCO_2$-eq and 8.2 $MtCO_2$-eq of CH_4 in 2025, respectively.

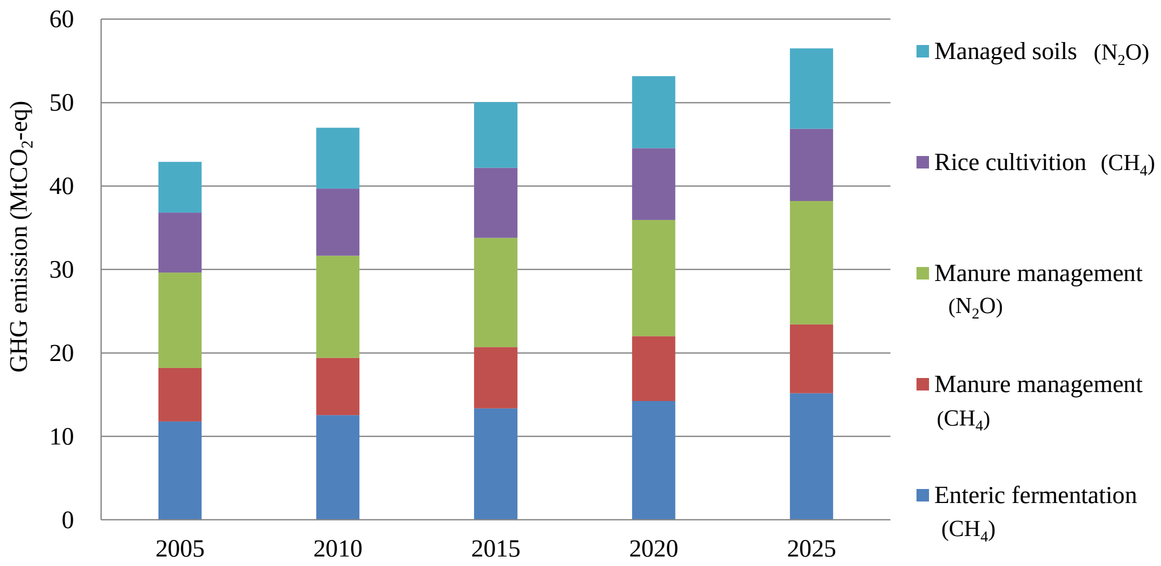


Fig. 6.4 Projected GHG emission from agriculture sector

Fig. 6.5 shows CO_2 emission from LULUCF sectors from 2005 to 2025. The trend shows gradual increase in GHG emission from 2005 to 2025 except 2015 level. In 2005, net emission from LULUCF sectors is estimated about 13.3 $MtCO_2$-eq, mainly from removal from soil (16.1 $MtCO_2$-eq), followed by the forest and grassland conversion (3.6 $MtCO_2$-eq) and carbon sequestration as forest and other woody biomass stocks (-6.5 $MtCO_2$-eq). The emission is estimated to significantly increase of 12% by 2010, due to substantial decrease in forestland area and considerable increase in settlement for growing population in the same period.

The emission trend will be discontinued by decreasing from the emission of 15 $MtCO_2$-eq in 2010 to 11.6 and 12.6 $MtCO_2$-eq by 2020 and 2025 respectively, with the government's several development, strategies, especially 20% increment of production forest after 2010 to 2021 (Ministry of Planning, 2010). Such government actions contribute to significant reduction in emission from forest and grassland conversion in this sector.

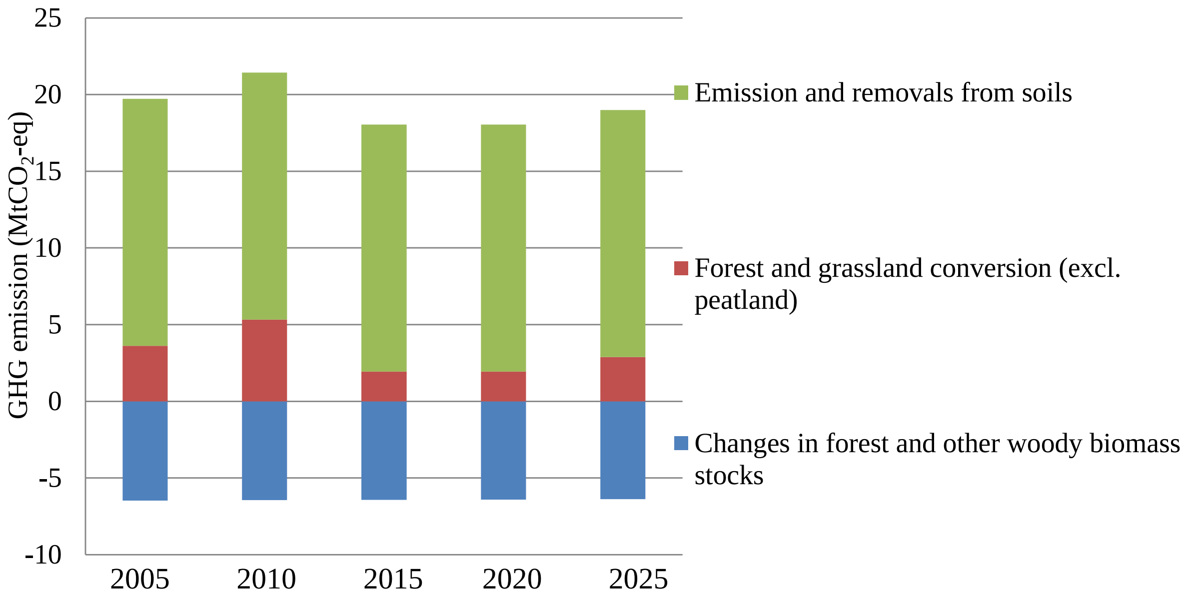


Fig. 6.5 Projected GHG emission from LULUCF sectors

6.6.1. GHG emission reduction in AFOLU sectors

Total mitigation potential from AFOLU sectors is shown in Table 6.16. About 28% of the GHG emission from AFOLU sectors can be reduced in AFOLU sectors at an emission tax of 10 US$/t$CO_2$-eq (agriculture sector) and mitigation cost 10 million US$ (LULUCF sectors) in 2025. In agriculture sector, midseason drainage in rice cultivation (MD), bioenergy from manure (BM) and replacement of roughage (RRC) with concentrates feed are expected to reduce 12.8 MtCO_2-eq at an emission tax of 10 US$/t$CO_2$-eq. In land use sector, 6.5 MtCO_2-eq of mitigation potential or 33% of emission reduction can be achieved under mitigation cost of 10 million US$ by 2025 through applying enhanced natural regeneration, long and medium rotational artificial reforestation (LRR) and enhanced natural regeneration (ENR) and reduced impact logging (RIL). Detailed of mitigation potential will be explained in chapter 7.

Table 6.16 Summary of GHG emission reduction from proposed measures in AFOLU sector

Reduction measures	GHG emission reduction ($MtCO_2$-eq)	(%)
1. Rice field management (Midseason drainage+Off-season incorporation of rice straw+Replace urea with ammonium sulphate) in agriculture sector	5	24%
2. Manure management (Dome digester for cooking fuel and light) in agriculture sector	4	21%
3. Enteric fermentation (Replacement of roughage with concentrated feed)	3	14%
4. Managed soil (High efficiency fertilizer application+Tillage and residue management) in agriculture sector	1	7%
5. Long rotational artificial reforestation + Enhanced natural regeneration+Reduced impact logging) in LULUCF sector	7	34%
Total GHG emission reduction ($MtCO_2$-eq)	19	100%
Total GHG emission ($MtCO_2$-eq) in 2025BaU	69	
Total GHG emission ($MtCO_2$-eq) in 2025CM	50	

However, it will take long time and enough funding from different national and international organizations to accept and implement reduction measures. Raising knowledge and changing behavioral attitude of the general public towards LCS is also an important issue for realization of the needs of its implementation in Bangladesh.

Chapter 7 Actions towards LCS development in Bangladesh

7.1. GHG emission and reduction

The annual GHG emission of Bangladesh is estimated 87.9 $MtCO_2$-eq in 2005. In 2025BaU the GHG emission will be increased to 309.8 $MtCO_2$-eq (240.7 $MtCO_2$-eq from energy sector and 69.1 $MtCO_2$-eq from AFOLU sectors) which is about 3.5 times larger than the emission in 2005. In 2025CM the GHG emission will be reduced to 182.4 $MtCO_2$-eq which is about 41% smaller than 2025BaU (Fig. 7.1). Power sector is the largest contributor of GHG emission that results the emission about 39% of total GHG emission. The next is residential sector 22% and agriculture sector 18% of total GHG emission in 2025BaU.

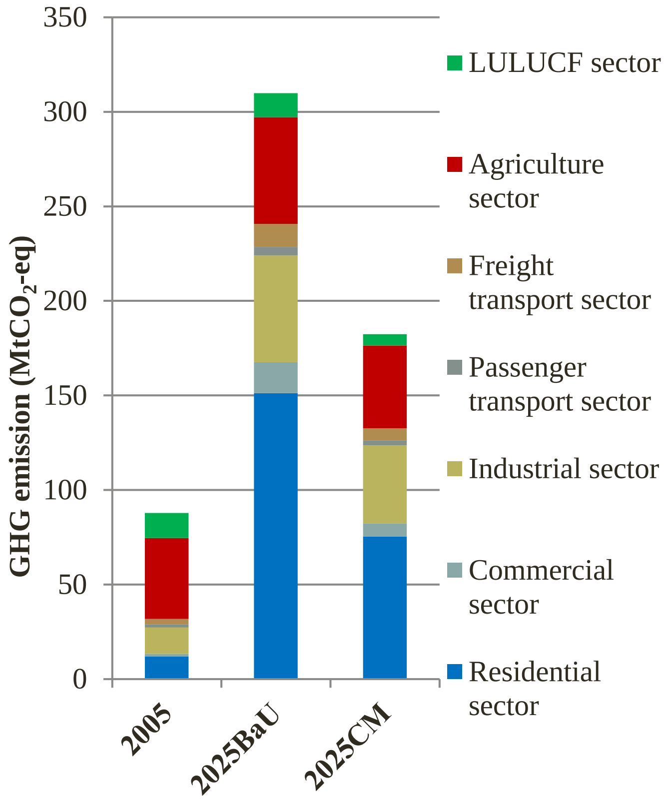


Fig. 7.1 Projected total GHG emission

Analyzing separately, in energy sector, power sector is also the largest contributor of

CO_2 emission that results the emission about 50% of total. The next are residential sector 28%, industrial sector 23%, commercial sector 7% and transport sector 7% in 2025BaU. The largest reduction of 70.8 $MtCO_2eq$ can be achieved by improving energy efficiency, where residential and commercial sectors accounted 58.6 $MtCO_2$-eq, industrial sector 5.1 $MtCO_2$-eq and transport sector (passenger and freight) 7.1 $MtCO_2$-eq. The second largest reduction can be achieved by power supply (reducing transmission loss and fuel switch to renewables and nuclear) which contributes about 30.9 $MtCO_2$-eq. A sum of fuel switch (from oil to gas) in all demand sectors also will be contributed 5.8 $MtCO_2$-eq where major share is covered by residential, commercial and industrial sector by 5%.

In AFOLU sectors, total GHG emission from agriculture and LULUCF sectors is expected to increase 1.2 times larger in 2025 than in 2005. In 2025, total GHG emission from agriculture sector will increase 1.3 times or 24% more than total GHG emission in 2005. Enteric fermentation in livestock is the largest contributor of 29% of total GHG emission from agriculture in 2005. Manure management generates the larger amount of emission in agriculture 6.4 $MtCO_2$-eq of CH_4 and 11.4 $MtCO_2$-eq of N_2O in 2005 and will increase to 8.2 $MtCO_2$-eq and 14.8 $MtCO_2$-eq in 2025 respectively. 29% of the emission can be reduced in agriculture at an emission tax of 100 US$/$tCO_2$-eq in 2025. Midseason drainage in rice cultivation, bioenergy from manure and replacement of roughage with concentrates feed are expected to reduce 12.8 $MtCO_2$-eq at an emission tax of 10 US$/$tCO_2$-eq.In LULUCF sectors, this model estimated the net emission of 12.6 $MtCO_2$-eq in 2025. In this sector, 13.7 $MtCO_2$-eq of mitigation potential or 100% of emission reduction can be achieved under mitigation cost of 50 million US$ by 2025 through applying enhanced natural regeneration, long and medium rotational artificial reforestation and medium rotational sal plantation.

In 2005, per capita GHG emission of Bangladesh is 0.63tCO_2-eq and in 2025BaU it will be increased up to 1.72tCO_2-eq or 2.8 times larger than in 2005. 2025BaU per capita GHG emission level nearly reaches the world's per capita GHG emission target 1.92tCO_2-eq of 2050. In this study, by adopting reduction measures, emission per capita can be reduced to 0.99tCO_2-eq in 2025CM (Fig. 7.2). GHG emission intensity in Bangladesh is 22.3 gCO_2-eq/taka in 2005. The GHG emission intensity will be reduced to 21.6 gCO_2-eq/taka in 2025BaU. In 2025CM the emission intensity will be further reduced to 12.7 gCO_2-eq/taka or 41% reduction from 2025BaU (Fig. 7.2).

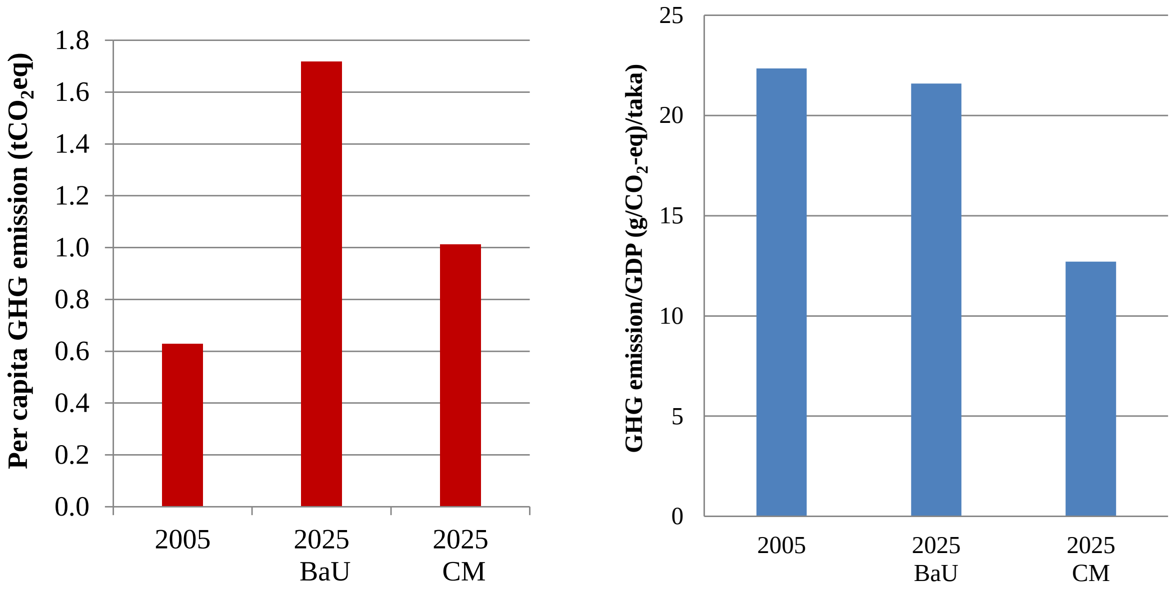


Fig. 7.2 Per capita GHG emission and GHG emission intensity

To reduce the GHG emission, the following reduction measures are essential;

Residential and commercial sector;

- Energy efficient lighting (compact fluoresce lights, CFL).
- Efficient cooking system (improved cooking stove).
- Efficient refrigerator.
- Efficient cooling system.

Industrial sector;

- Energy efficient furnace, steam boiler and motor.
- Fuel switch from oil to natural gas.

Transport sector;

- Energy efficiency improvement in old and reconditioned engines of road vehicles.
- Modal shift from private vehicle to public transport and railway.

Power sector;

- Fuel Switch from coal to renewable and nuclear.
- Reduction of transmission loss.

Agricultural sector;

- Enteric fermentation.
- Manure management.
- Rice cultivation.
- Managed soil.

LULUCF sectors;

- Long rotational artificial reforestation.
- Medium rotation participatory coastal plantation.
- Medium rotation sal plantation.
- Medium rotational artificial reforestation.
- Short rotational participatory woodlot plantation.
- Enhanced natural regeneration
- Reduced impact logging

Fig. 7.3 shows the mitigation potential achieved by applying several reduction measures.

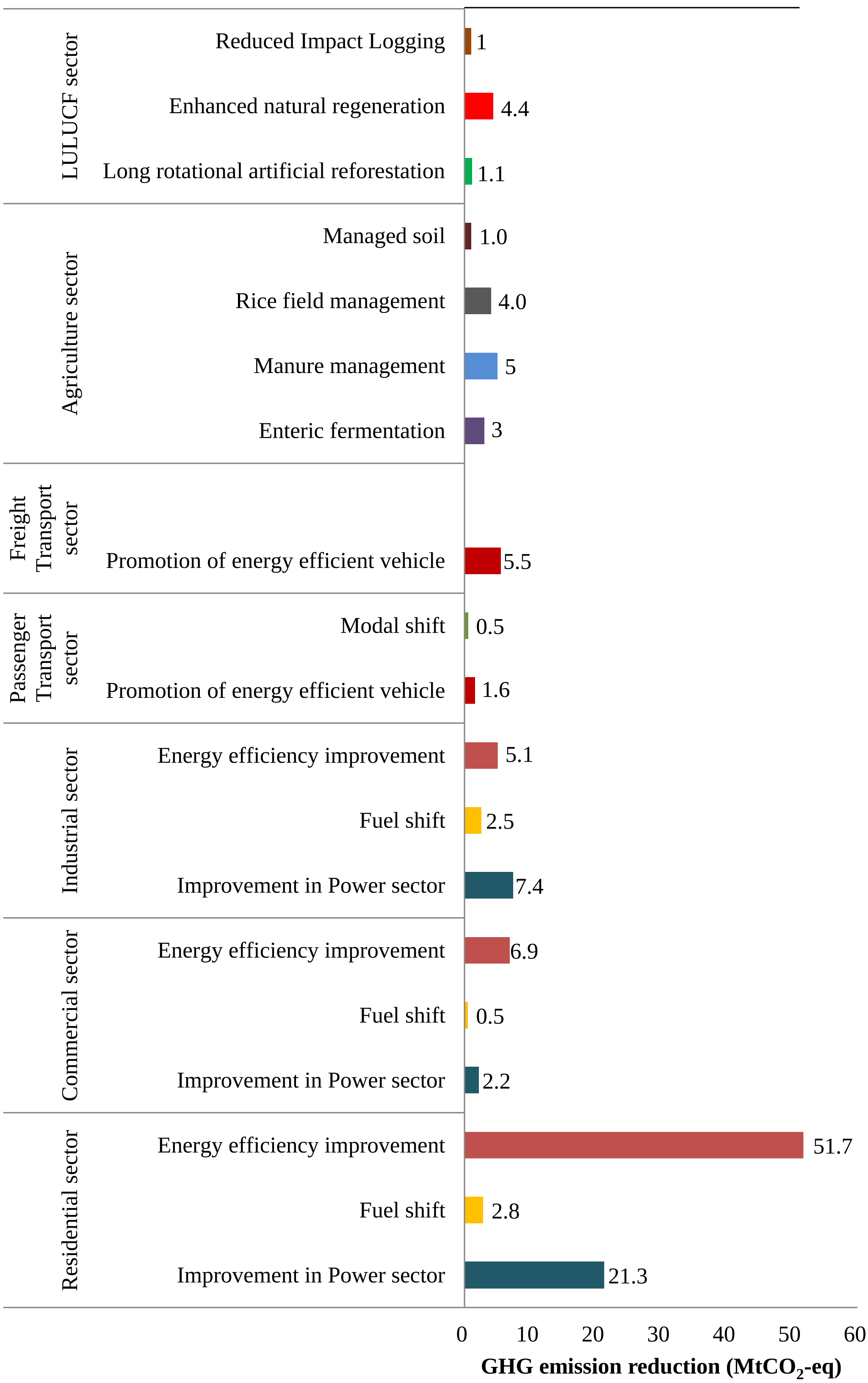


Fig. 7.3 Total GHG emission reduction

7.2. Proposed actions towards energy and AFOLU sectors

7.2.1. Residential sector

The increment of energy demand in the residential sector depends on the population growth, number of households and per capita GDP. Population will increase to 180 million and number of household to 43 million in 2025. In 2025BaU, energy demand in residential sector will be increased to 42Mtoe which is about 3.7 times larger than in 2005. CO_2 emission will be increased to 151 $MtCO_2$-eq that is 12.8 times larger than in 2005. Fig. 7.4 shows emission reduction in residential sector. About 76 $MtCO_2$-eq of CO_2 emission reduction can be achieved by adopting reduction measures e.g. energy efficiency improvement, fuel shift and improvement in power sector (it reduces emission from electricity generation which is consumed by residential sector). Efficient lighting, refrigerator and cooling have the most potential and cover 53 $MtCO_2$-eq or 71% of reduction of CO_2 emission in this sector. Fig. 7.5 shows the percentage of CO_2 emission reduction by energy service in residential sector in total GHG emission reduction. Residential sector including power supply will contribute about 60% reduction of CO_2 emission in total GHG emission. Using photo voltaic lights e.g. CFL in lighting will share highest reduction of 28% in total GHG emission reduction.

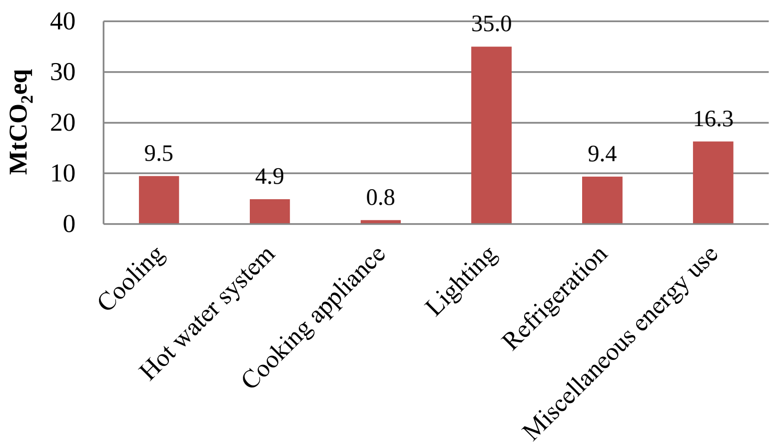


Fig. 7.4 CO_2 emission reduction by residential energy services in energy sector

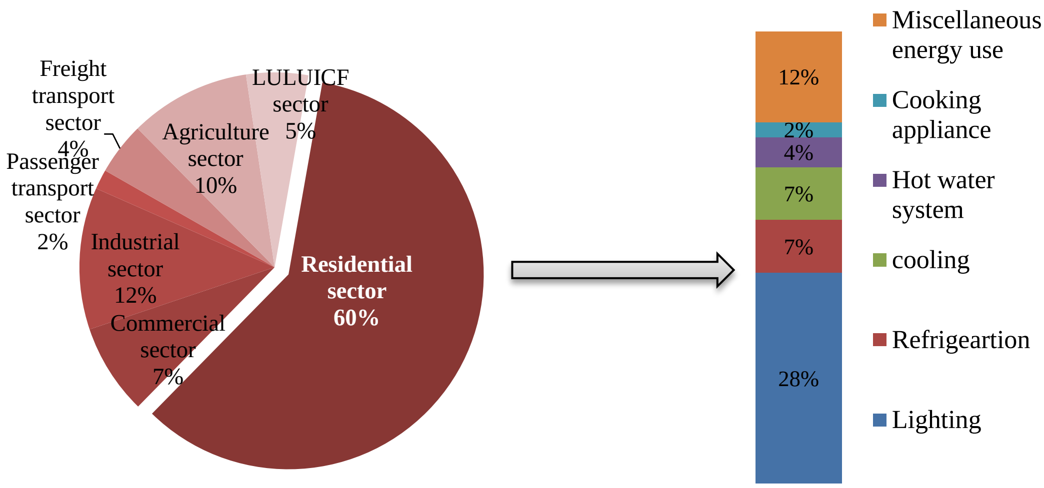


Fig. 7.5 Percentage of GHG emission reduction of residential sector in total GHG emission reduction

7.2.2. Commercial sector

Energy demand in commercial sector is driven by growth of tertiary industry output. In 2025BaU, the output of the tertiary industry will be increased 3.9 times larger than in 2005 and energy demand will be increased to 2.8Mtoe and CO_2 emission 16 $MtCO_2$-eq, which is about 9.5 and 11.6 times greater than 2005. In 2025CM, reduction measures e.g. improvement in energy efficiency (electric devices, insulation buildings), efficiency improvement in power sector and fuel switch are the potential options for CO_2 emission reduction, reduces about 9.0 $MtCO_2$-eq and contributed about 8% of the total emission reduction from energy sector. Fig. 7.6 shows the reduction of CO_2 emission by energy service. Previous section show that interestingly the energy consumption of commercial sector will be increased drastically compared to residential sector due to increased energy consumption in different commercial sectors (health, education, and real-estate) in 2025BaU. This increase will be more than proportional to increase of number of household and output of tertiary industry because, when per capita GDP increased, energy demand per household and per output also will increase. It is consistent with observed trend of energy demand in Bangladesh since 2000. Fig. 7.7 shows the percentage of CO_2 emission reduction of 7% by energy service of commercial sector including power supply in total GHG emission reduction.

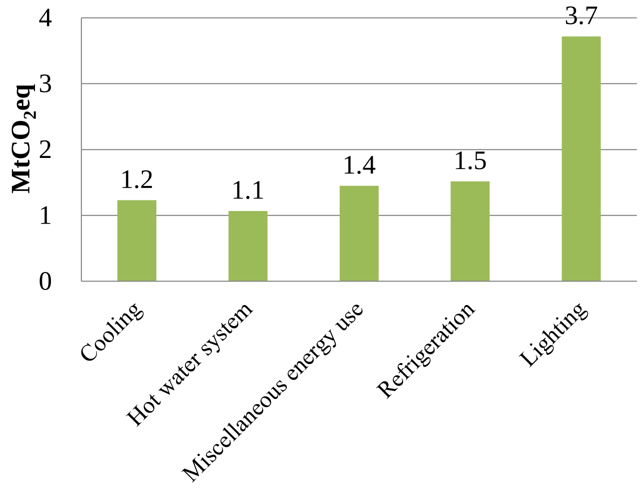


Fig. 7.6 CO_2 emission reduction by commercial energy services in energy sector

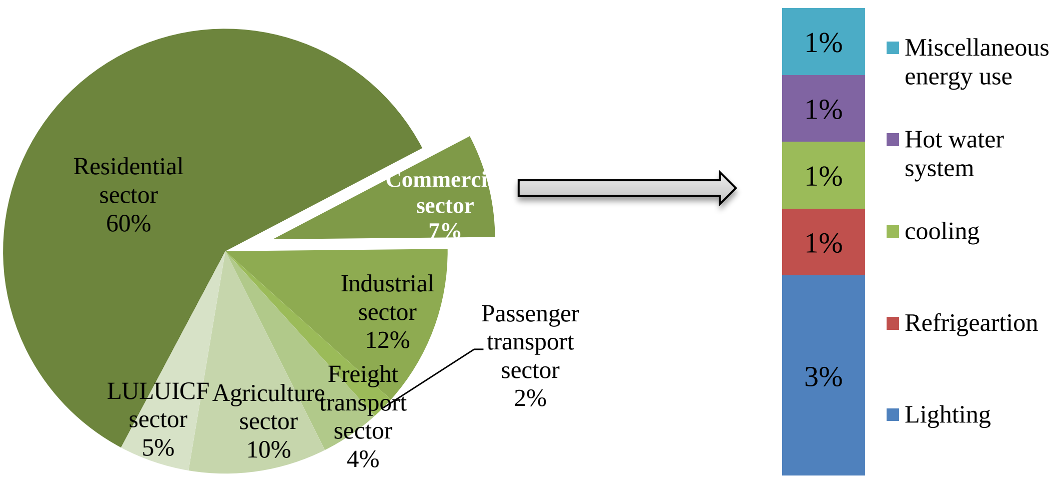


Fig. 7.7 Percentage of GHG emission reduction of commercial sector in total GHG emission reduction

7.2.3. Industrial sector

Industrial sector" in this study comprises of primary and secondary industries. This report assumed that GDP growth rate will be 7% by 2025. The outputs of the industries will be increased to 20,464 billion taka in 2025, which is 3.5 times larger than 5,897 billion taka in

2005. Energy demand in industrial sector increases to 13.1Mtoe in 2025BaU from 3,700ktoe (2005). Without adopting any low-carbon measure in 2025BaU; the CO_2 emission will be increased to 56 $MtCO_2$-eq, about 4 times larger than in 2005. In 2025CM, by adopting reduction measures e.g. energy efficiency improvements and fuel switch, CO_2 emission will be decreased to 41 $MtCO_2$-eq. Fig. 7.8 shows the reduction options by energy services for emission reduction in industry. Fig. 7.9 shows that industry including power supply contributes 12% CO_2 emission reduction in total GHG emission reduction.

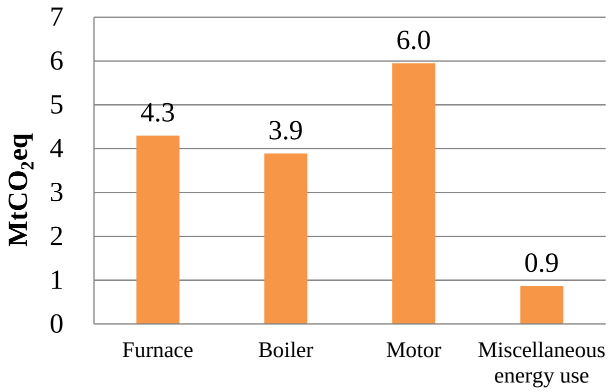


Fig. 7.8 CO_2 emission reduction by industrial energy services in energy sector

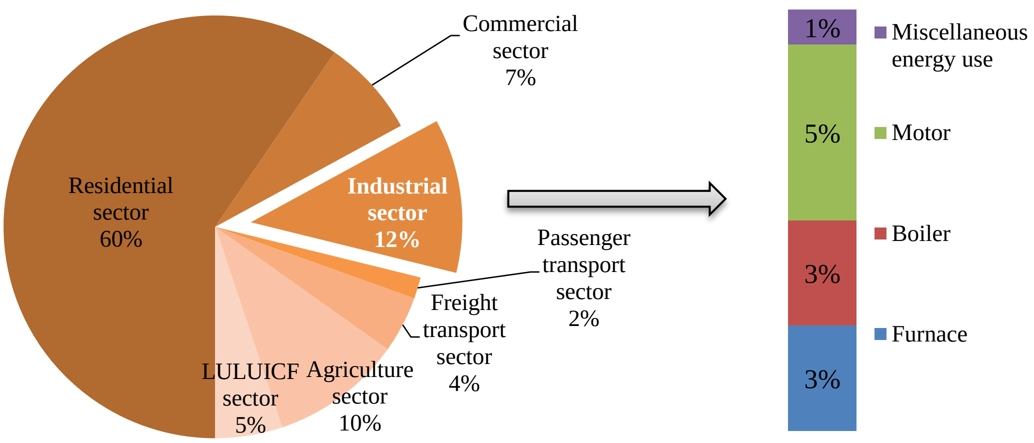


Fig. 7.9 Percentage of GHG emission reduction of industry sector in total GHG emission reduction

7.2.4. Power sector

In this study, 2025BaU followed the projected composition of energy mix in existing planning, (Ministry of planning, 2010) without applying any renewable energy except hydro power. On the other hand, in 2025CM, reduction measures e.g. reduction of transmission loss and fuel switch from non-renewable to renewable energy (solar, hydro, nuclear energy) reduced the emission by 30.9 MtCO_2-eq and contributed about 29% of total CO_2 emission reduction. In 2025CM, nuclear energy and renewables (solar, wind) and less share of coal reduce CO_2 emission. Fig. 7.10 shows the CO_2 emission in 2025BaU and emission reduction of 52% in 2025CM in power sector, considering the application all sectors' reduction measures in power. GHG emission reduction from power sector contributed 24% of total GHG emission reduction. In supply side, 40% of electricity savings can be achieved of which 24% and 16% of coal and natural gas savings from electricity generation, contribute indirectly in the total energy savings respectively. Composition of possible low-carbon energy mix for power generation and percentage of electricity consumption by end-use sectors are shown in Fig. 7.11.

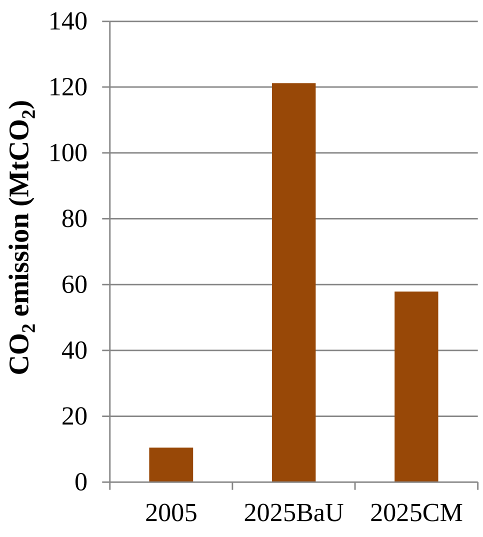


Fig. 7.10 CO_2 emission from power sector

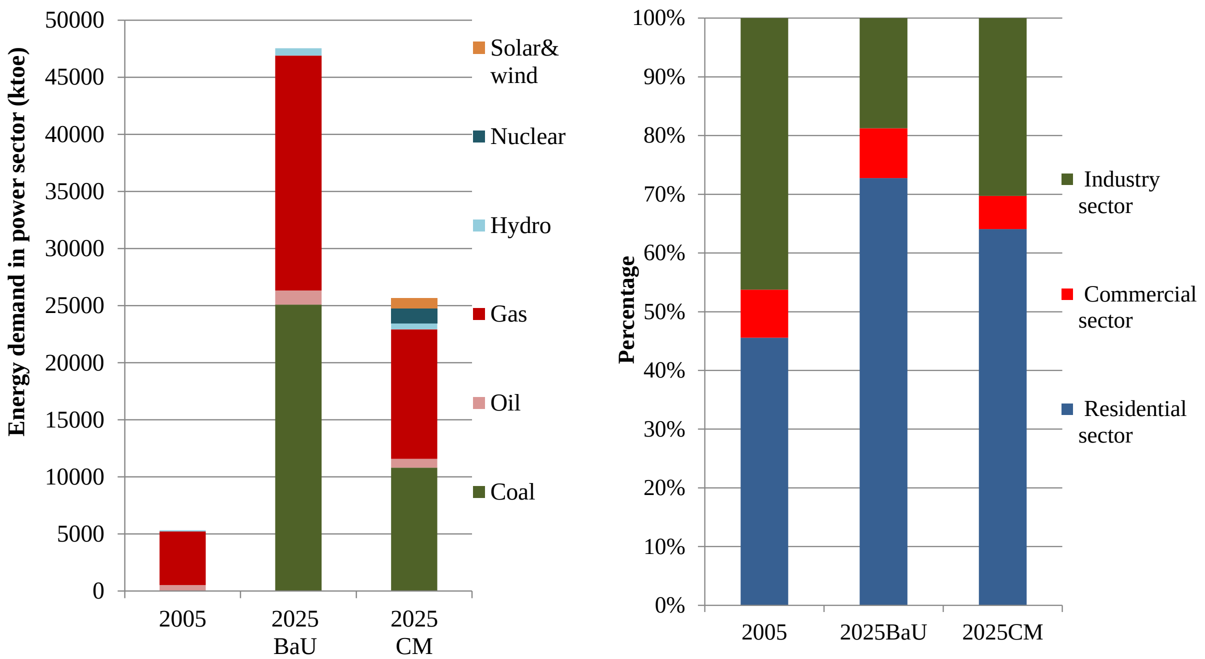


Fig. 7.11 Energy mix in power generation and power consumption by end-use sectors

7.2.5. Transport sector

In passenger transport sector, the transport volume will be increased from 361 billion passenger-km in 2005 to 663 billion passenger-km in 2025, resulting about 1.8 times larger than 2005. Passenger transport volume increases due to the rapid growth of population and increased use of private vehicles. In 2025BaU, the energy demand will be increased from 530ktoe to 1.5Mtoe or 2.8 times larger than 2005. The CO_2 emission from passenger transport will be increased to 4.6 $MtCO_2$-eq in 2025BaU from 1.6 $MtCO_2$-eq in 2005. However, in 2025CM, by adopting possible reduction measures e.g. energy efficiency improvement of vehicle and modal shift (Fig. 7.12) the emission will be reduced to 2.5 $MtCO_2$-eq which contributes about 3% of total CO_2 emission reduction.

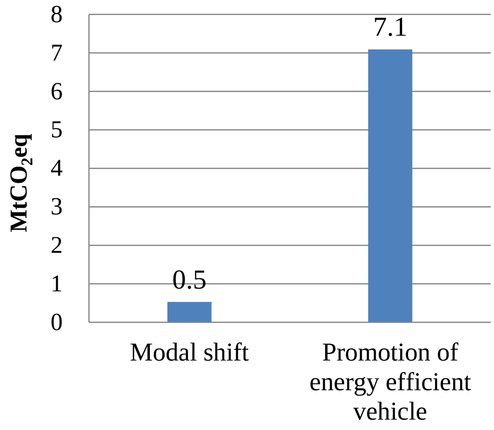


Fig. 7.12 CO_2 emission reduction by energy services in transport sector

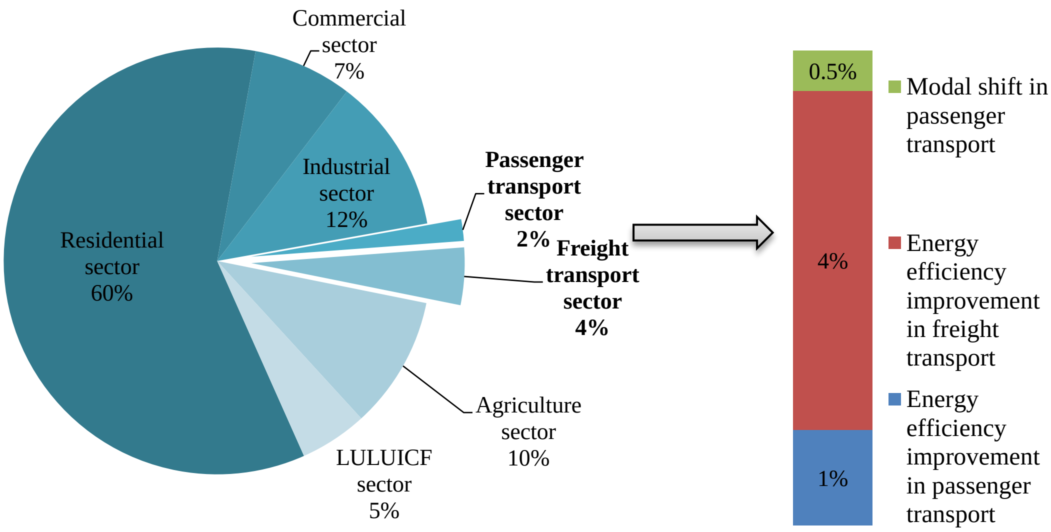


Fig. 7.13 Share of GHG emission reduction of transport sector in total GHG emission reduction

In freight transport sector, freight transport volume will be increased from 20 billion ton-km in 2005 to 91 billion ton-km in 2025. Energy demand and CO_2 emission in freight transport will be increased to 3.9Mtoe and 12 $MtCO_2$-eq in 2025BaU. 16% of freight transport depended on inland waterway and 80% on road vehicle in 2005, however, in 2025BaU, share of road vehicle is increased to 84% while share of inland waterway decreases, due to the improvement in structural improvements of road and bridge construction in the country (e.g. Padma multipurpose bridge (2011-2015) which will facilitate the social, economic and industrial development of underdeveloped regions of the country). In CM2025, energy efficiency improvement contributes reduction of 5.5 $MtCO_2$-eq or 5% of the total emission reduction (Fig. 7.12). In total GHG emission reduction, passenger and freight transport results small amount of 2% and 4% of GHG emission reduction respectively (Fig. 7.13).

7.2.6. Agriculture sector

Fig. 7.14 shows the breakdown of GHG mitigation potential by applied technologies at various emission taxes in 2025. At emission tax of 0 US$/t$CO_2$-eq, 10 $MtCO_2$-eq of mitigation potential can be achieved in 2025. Three types of mitigation technologies taking at zero cost are called “No Regret Technologies” (an emission tax is less than 0 US$/t$CO_2$-eq): Midseason drainage (MD), bioenergy from manure (BM) and replacement of roughage with concentrates (RRC), contributing 3.2 $MtCO_2$-eq, 4.1 $MtCO_2$-eq and 2.7 $MtCO_2$-eq of mitigation potential respectively. At an emission tax of 10 US$/t$CO_2$-eq, the cumulative mitigation potential in 2025 is 12.8 $MtCO_2$-eq (23% of total baseline emission in 2025) by summing the mitigation technologies. MD, off-season incorporation of rice straw (OIR) for rice cultivation, BM and RRC for livestock sector are the most effective mitigation technologies to gain the higher mitigation potential. 84% of the total mitigation potential can be achieved through applying the four technologies in combination.

Moreover, at emission taxes of 100 US$/t$CO_2$-eq and >100 US$/tCO_2-eq, the mitigation potential increase significantly to 16.6 $MtCO_2$-eq and 20.4 $MtCO_2$-eq (29% and 36% of total baseline emission in 2025) respectively. High mitigation costs will generate higher mitigation potentials. At emission taxes of 100 US$/t$CO_2$-eq, the most contributors are BM for livestock manure and MD for rice cultivation, which reduce 7.7 $MtCO_2$-eq (47% of total mitigation potential in agricultural sector in 2025). Looking at each emission source, technologies for rice cultivation; MD, RAS and OIR contribute 6.7 $MtCO_2$-eq (38% of total mitigation potential) in total and technologies for livestock sector; RRC for enteric fermentation and BM for manure management have high mitigation effects, resulting 6.0 $MtCO_2eq$ (34% of total mitigation potential) at an emission tax of 100 USD/tCO_2eq. Relatively expensive technologies for each emission source like Slow-release fertilizer (SRF), high genetic merit (HGM) and daily spread of manure (DSM) are possible to be applied only at 100 and >100 USD/tCO_2eq because they are not selected under a low emission tax. DSM is applied only at >100 US$/$tCO_2$-eq emission tax because total technology cost including emission tax of DSM become lower than that of BM at high emission tax and BM is replaced by DSM.

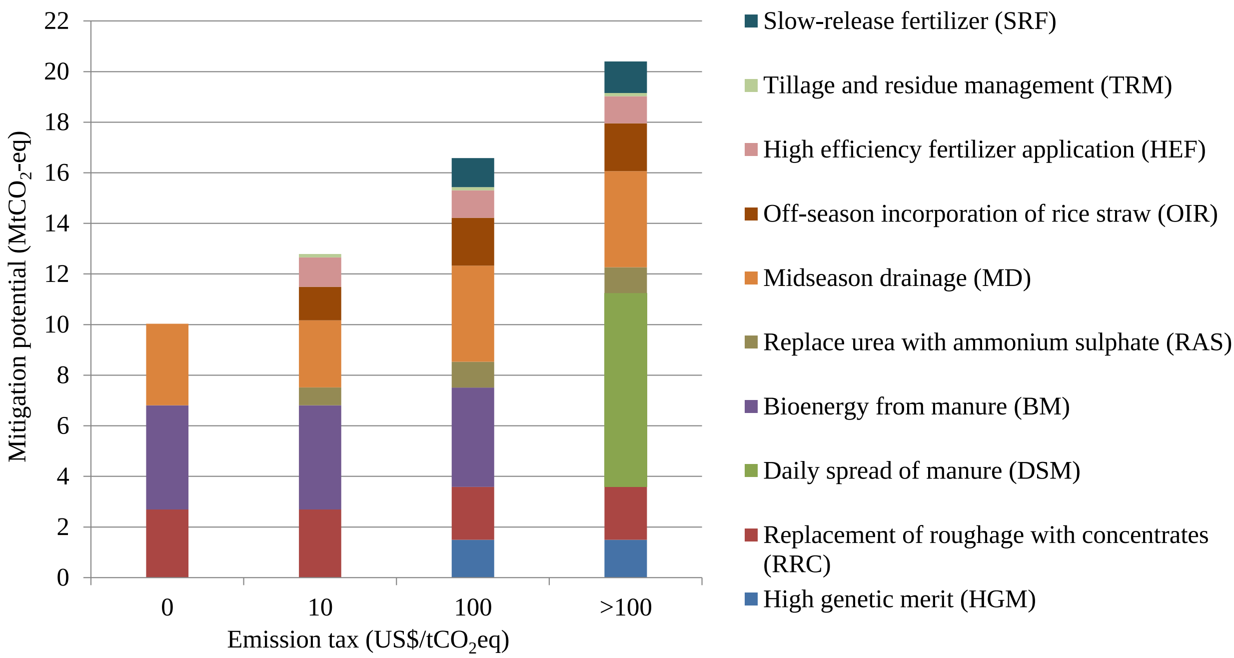


Fig. 7.14 GHG emission reduction in agriculture sector in 2025

Fig. 7.15 shows time trend of the mitigation potential under 10 US$/$tCO_2$-eq of emission tax. Mitigation potential is expected to increase from 10.9 $MtCO_2$-eq to 12.8 $MtCO_2$-eq from 2010 to 2025. Technologies for rice cultivation MD, RAS and OIR showed an only 9% increase (4.3 $MtCO_2$-eq to 4.7 $MtCO_2$-eq) in mitigation potential in the same period because harvested area of rice is expected to slightly increase in the future. In contrast, BM and RRC from livestock sector showed 17% increase in mitigation potential in the same period because great increase in number of livestock in the country.

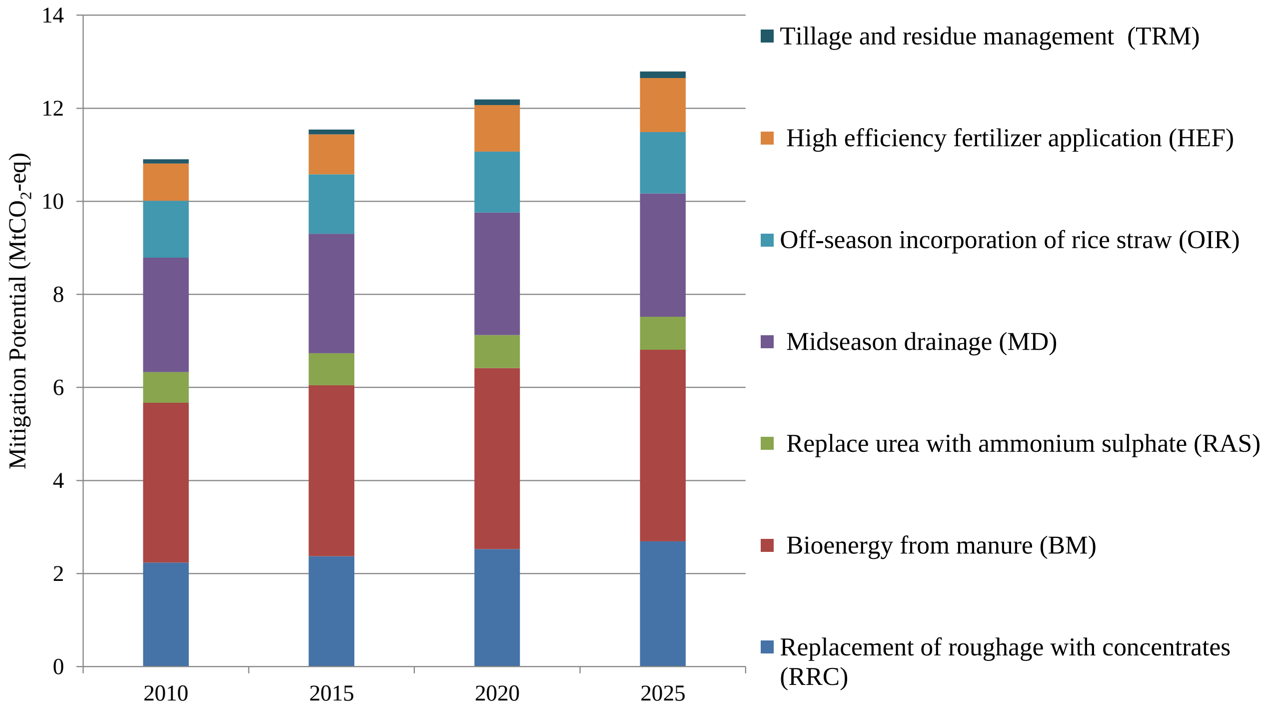


Fig. 7.15 Mitigation potential under 10 US$/$tCO_2$-eq

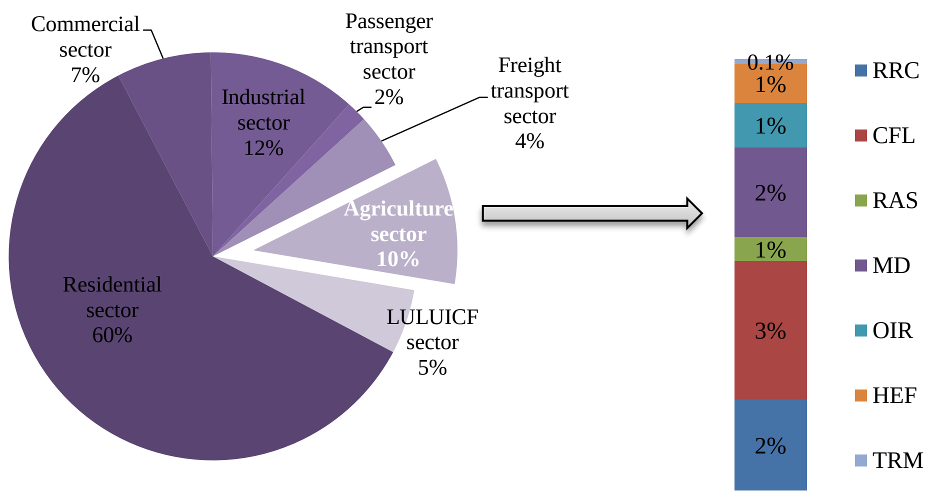


Fig. 7.16 Share of GHG emission reduction of agriculture sector in total GHG emission reduction

As a result, the DSM is expected to contribute 40% of total mitigation potential in 2025. This study estimated 12.8 $MtCO_2$-eq at an emission tax of 10 US$/$tCO_2$-eq or 10% of mitigation potential in agriculture sector in total GHG emission reduction (Fig. 7.16).

7.2.7. LULUCF sectors

Fig. 7.17 shows the mean mitigation potential under a wide range of mitigation cost of 0.1 million US$ to 500 million US$ from 2010 to 2025. At an emission cost of 1.0 million US$, only Reduced impact logging (RIL) and enhanced natural regeneration (ENR) are applied as the most cost-effective technologies. In addition to those two technologies, long rotational artificial reforestation (LRR) is applied at emission cost of 10 million US$ because LRR is the most cost-effective compared to other reforestations/plantations. At 50 million US$, medium rotational artificial reforestation (MRR) and medium rotation sal plantation (MRP) are applied and have a great contribution to mitigation of 3.4 $MtCO_2$-eq and 2.7 $MtCO_2$-eq respectively, resulting 52% of emission reduction from 2025 LULUCF emission level. Mitigation potential of 20.5 $MtCO_2$-eq has resulted at mitigation cost of 100 million US$. At this cost, ENR has the highest mitigation potential of 26%, which is followed by MRR and MRP of having 23% and 21% of mitigation potential in total respectively. At mitigation cost of 500 million US$, 39.6 $MtCO_2$-eq of mitigation potential can be achieved in total. This is called as technological mitigation potential in LULUCF sectors. This is equal to 3.0 times or 66% greater than of total emission from LULUCF in 2005 and 20% higher than the total emission from energy sector in 2005 (Energy sector: 31.7 $MtCO_2$-eq) in Bangladesh. This suggests that LULUCF mitigation technologies have a great potential to remove the amount of emission from other sectors. At the same cost, reforestation and plantations (LRR, MRP and MRR, SRP and SRR) contribute 30.5 $MtCO_2$eq in total and ENR and RIL contribute mitigation of 9.1 $MtCO_2$-eq in total. In contrast, short rotational participatory woodlot plantation (SRP) and short rotational artificial reforestation (SRR) finally contribute mitigation of 6.7 $MtCO_2$-eq at 500 million US$ mitigation cost. This shows that LRR has much more cost effective than SRP/SRR even though they will take a long time (40 years) to make effects. From this analysis, short-, medium-and long-term mitigation targets has been announced in some countries, but for LULUCF sectors, a long-term target (from 35 to 40 years) and a long-term viewpoint in technology selection will play a key role in GHG emission mitigation in Bangladesh. At 10 million US$, 6.5 $MtCO_2$eq (RIL 1.0 $MtCO_2$-eq, ENR 4.4 $MtCO_2$-eq and LRR 1.1 $MtCO_2$-eq) contributed 5% in total GHG emission reduction.

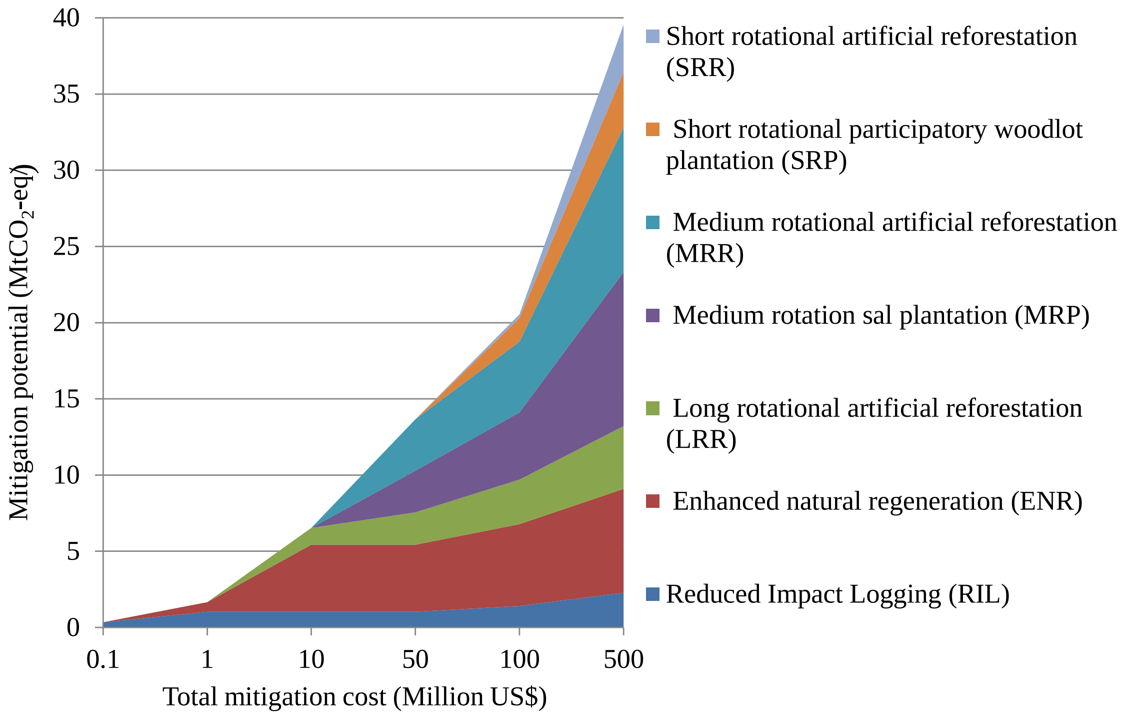


Fig. 7.17 Mitigation potential in LULUCF sectors

7.2.8. Summary of total GHG emission reduction in Bangladesh

Energy efficiency improvement contributes the highest emission reduction potential of 64 $MtCO_2$-eq or 50% of the total GHG emission reduction. Secondly, fuel switch from coal to natural gas, promotion of renewable energy as low-carbon energy mix and reduce transmission loss in power sector are potential measure to reduce 31 $MtCO_2$-eq. Brief overviews of possible measures and emission reductions are shown in Table 7.1.

Table 7.1 Summary of GHG emission reduction from proposed measures

Reduction measures	**GHG emission reduction ($MtCO_2$-eq)**	**(%)**
Energy sector	**108$MtCO_2$-eq**	
1. Energy efficiency improvement in residential and commercial sector	59	46%
2. Energy efficiency improvement in industrial sector	5	4%
3. Fuel switch in residential, commercial and industrial sector	6	5%
4. Promotion of energy efficient vehicles (passenger + freight transport)	7	6%
5. Modal shift in passenger transport sector	1	0.4%
6. Fuel switch and reduction of transmission loss in power sector	31	24%
AFOLU sectors	**19$MtCO_2$-eq**	
7. Rice field management (Midseason drainage + Off-season incorporation of rice straw + Replace urea with ammonium sulphate) in agriculture sector	5	4%
8. Manure management (Dome digester for cooking fuel and light) in agriculture sector	4	3%
9. Enteric fermentation (Replacement of roughage with concentrated feed)	3	2%
10. Managed soil (High efficiency fertilizer application + Tillage and residue management) in agriculture sector	1	1%
11. Long rotational artificial reforestation + Reduced impact logging + Enhanced natural regeneration in LULUCF sector	7	5%
Total GHG emission reduction ($MtCO_2$-eq)	**127**	**100%**
Total GHG emission ($MtCO_2$-eq) in 2025BaU	**310**	
Total GHG emission ($MtCO_2$-eq) in 2025CM	**182**	

Power sector is the largest contributor of GHG emission that results the emission about 39% of total GHG emission. The next is residential sector 22% and then agriculture sector 18% in 2025BaU. GHG emission can be reduced about 41% in 2025CM by adopting some effective and feasible reduction measures. Fig. 7.18 shows the largest reduction of 54.5 $MtCO_2$eq or 43% of reduction can be achieved by improving energy efficiency, fuel switch and electricity supply in residential sector. Residential sector (in combination with power sector) is the highest contributor in GHG emission reduction potential of 60%, in which lighting and improved cooking stove comprised of 43% of potential in 2025CM case. The second largest reduction can be achieved by power supply (reducing transmission loss and fuel switch to renewables and nuclear) which contributes about 30.9 $MtCO_2$-eq or 24% of total reduction. 10% of the GHG emission can be reduced in agriculture at an emission tax of 10 US$/$tCO_2$-eq in 2025. The model estimated 6.5 $MtCO_2$-eq of mitigation potential or 5% of emission reduction can be achieved under mitigation cost of 10 million US$ by 2025 through applying measures for GHG emission reduction.

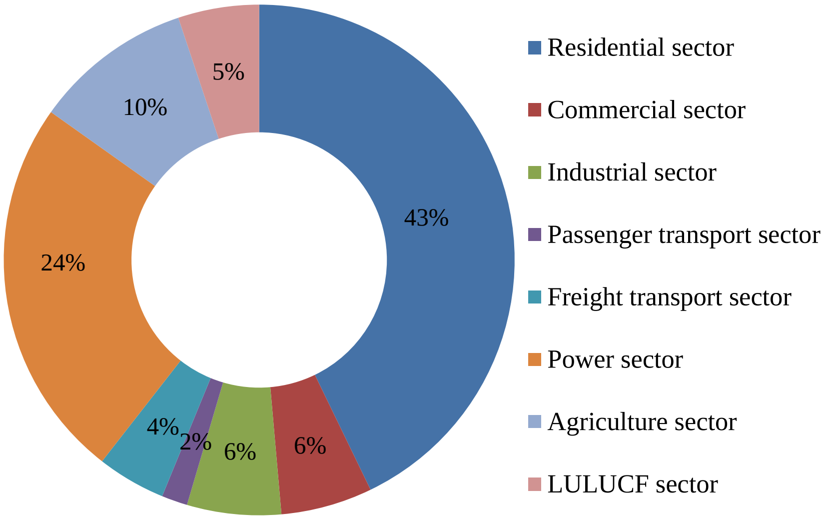


Fig. 7.18 Sectors contribution in total GHG emission reduction

7.2.9. Summary of energy savings from proposed measures in Bangladesh

Sector-wise energy savings achieved by energy service type through applying above feasible reduction measures is explained in this section. Socio-economic factors and growth of energy intensive industries are the drivers of increase in energy demand in Bangladesh. Energy demand is expected to increase to 46Mtoe of which residential sector results 31Mtoe or 66% of total increase in 2025BaU from baseline energy demand (Table 7.2). Future growth of energy service demand such as hot water heating and lighting cause this large increase in energy demand. Secondly, industry sector will consume 9Mtoe in 2025BaU due to the growth of manufacturing industry, comprising 3.5 times larger than in 2005 at GDP growth rate of 7%. As Bangladesh has experienced a significant decline in agriculture based industries (paper, cotton, jute etc.) and is switching to energy intensive ready-made garments industries (Munim et al., 2010). Transport sector in Bangladesh is heavily dependent on imported oil product (petroleum), resulting 4Mtoe or 9% of total energy increase in 2025BaU. The increased use of petroleum products of 7% in freight transport sector indicates the growth in industrial production (manufacturing industry) of the country. Selection and application of reduction measures mostly depend on country's socio-economic condition and potential energy service type and sector to achieve larger reduction in energy demand. This study attempts to apply reduction measures and estimates energy demand reduction of 16Mtoe of which residential sector covers 10.3Mtoe or 67% of reduction in 2025CM. In the context of Bangladesh, efficient lighting (compact fluorescent light, CFL), kitchen (improved cooking stove) and other electric appliances are the most potential measures, provide 25%, 13% and 16% of energy demand reduction in 2025CM respectively. According to ongoing initiatives, Bangladesh Govt. distributes CFL bulbs among consumers in exchange for incandescent bulbs to save up to 400 MW of electricity a day (Ministry of power, Energy and Mineral Resources, 2010) and has planned to distribute about 22 million CFL bulbs under World Bank aided 43 million US$ project. Hossain and Badr (2007) reports that improved cooking stoves developed by Institute of Fuel Research and Development (IFRD) and Bangladesh Council of Scientific and Industrial Research (BSCIR) can save 60-65% of energy compared to traditional mud stoves. Bangladesh Power Development Board (BPDB) and Rural Electrification Board (REB) with other institutions are continuing to improve efficiency of other electric appliances (Hossain and Badr, 2007). 14% of energy saving can be achieved by energy efficiency improvement in old and reconditioned engines of road vehicles in passenger and freight transport. In passenger and freight transport railway, this study assumed the same energy efficiency of BaU in CM case, however, in 2025CM case modal share of passenger transport rail is increased to enhance rail usage for less CO_2 emission in future. Therefore, this transport mode accounted no energy savings in CM case. Efficient furnace and boiler in industry sector can save about 2Mtoe of energy in 2025CM. Energy efficiency improvement of electrical appliances and improvement in sector, reduces energy demand from electricity generation which is consumed by different sectors. This study assumed same energy efficiency in CM case as BaU; therefore, this energy service accounted no energy saving in 2025CM.

Table 7.2 Summary of energy saving from proposed measures (ktoe)

Sector	Energy service	Energy increase in 2025BaU	Share in total energy increase	Energy increase in 2025CM	Share in total energy increase	Energy saving 2025(BaU -CM)	Energy saving share
Residential sector	Cooling	1,386	3%	600	2%	786	5%
	Hot water heating	10,552	23%	10,102	33%	450	3%
	Kitchen	2,866	6%	830	3%	2,036	13%
	Lighting	7,244	16%	3,366	11%	3,878	25%
	Refrigeration	1,583	3%	877	3%	706	5%
	Other electric appliances	6,952	15%	4,499	15%	2,453	16%
Commercial sector	Hot water heating	897	2%	652	2%	244	2%
	Kitchen	554	1%	392	1%	162	1%
	Lighting	419	1%	68	0%	351	2%
	Refrigeration	237	1%	118	0%	119	1%
	Other electric appliances	265	1%	166	1%	99	1%
Industry sector	Cooling	153	0%	43	0%	111	1%
	Direct heat (furnace)	2,608	6%	1,531	5%	1,077	7%
	Steam boiler	3,434	7%	2,953	10%	482	3%
	Motor	1,666	4%	1,600	5%	66	0%
	Other electric appliances	1,659	4%	1,659	5%	0	0%
Transport sector	Road Vehicle	3,363	7%	1,143	4%	2,220	14%
	Railway	275	1%	336	1%	(61)	0%
	Waterway	331	1%	9	0%	322	2%

Electricity and oil product (kerosene) use for lighting in residential sector can save 16% and 9% of their consumption in 2025CM respectively. This sector also has the potentiality to reduce 6% of biomass consumption for cooking specially use in rural areas through introducing improved cooking stove. Reduction measures in industry sector show potentiality of 7% and 6% of reduction in natural gas use for furnace and steam boiler in

2025CM respectively. Petroleum product use in passenger and freight transport sector show larger potential of 14% energy saving in this sector through applied measures. In supply side, 40% of electricity savings can be achieved of which 24% and 16% of coal and natural gas savings contribute indirectly in the total energy savings respectively. I can conclude that residential sector is the most potential sector and contributes the highest energy savings of 67% by 2025. Efficient lighting (CFL bulb) and cooking (improved stove) in residential sector resulting 38% of energy saving in combination, can be recommended as appropriate measures for developing sustainable energy system for Bangladesh. Table 7.3 shows possible future energy saving share in residential sector by fuel.

Table 7.3 Possible energy saving by fuel

Sector	Energy service	Oil	Natural gas	Biomass	Electricity
Residential sector	Lighting	9%			16%
	Cooking	3%	4%	6%	
	Hot water heating	2%		6%	1%
	Cooling				5%
	Refrigeration				5%
	Other electric appliances	2%	9%		5%

7.2.10. Proposed package of reduction measures for LCS development in Bangladesh

To develop LCS in Bangladesh, a package of reduction measures is formulated based on the above projection and Outline Perspective plan of Bangladesh, Making Vision 2021 a reality (Ministry of Planning, 2010); National Energy Policy (Ministry of Power, Energy and Mineral Resources, 2004); National Renewable Energy Policy (Ministry of Power, Energy and Mineral Resources, 2008) and Strategic Transportation Plans (Ministry of Communication, 2010) (Fig. 7.19). Energy efficiency improvements is the single largest prospective deliverer of GHG emission reduction, due to its high potential of reducing energy demand and contributes to the universal goal of sustainable development for the country. Agriculture and forestry are significant sectors for a large GHG emission and are expected to play fundamental role in providing high mitigation potential by applying several mitigation technologies in AFOLU sectors in future. These research findings are likely to be the first trial for providing essential information on GHG emission and mitigation potential and also be the preliminary step for promotion of policies and strategies in AFOLU sectors of Bangladesh.

These measures are emphasized on fuel switch, introduction of renewable and nuclear energy in power sector, improve the energy efficient equipment, increment of public transport and improve traffic management system, sustainable agricultural system, soil management and increment of forest cover by reforestation program. This package can play core role in policy development and initiate discussion on proposing a trading system based on carbon taxes levied against countries failing to meet emission reduction targets at a reassessment period.

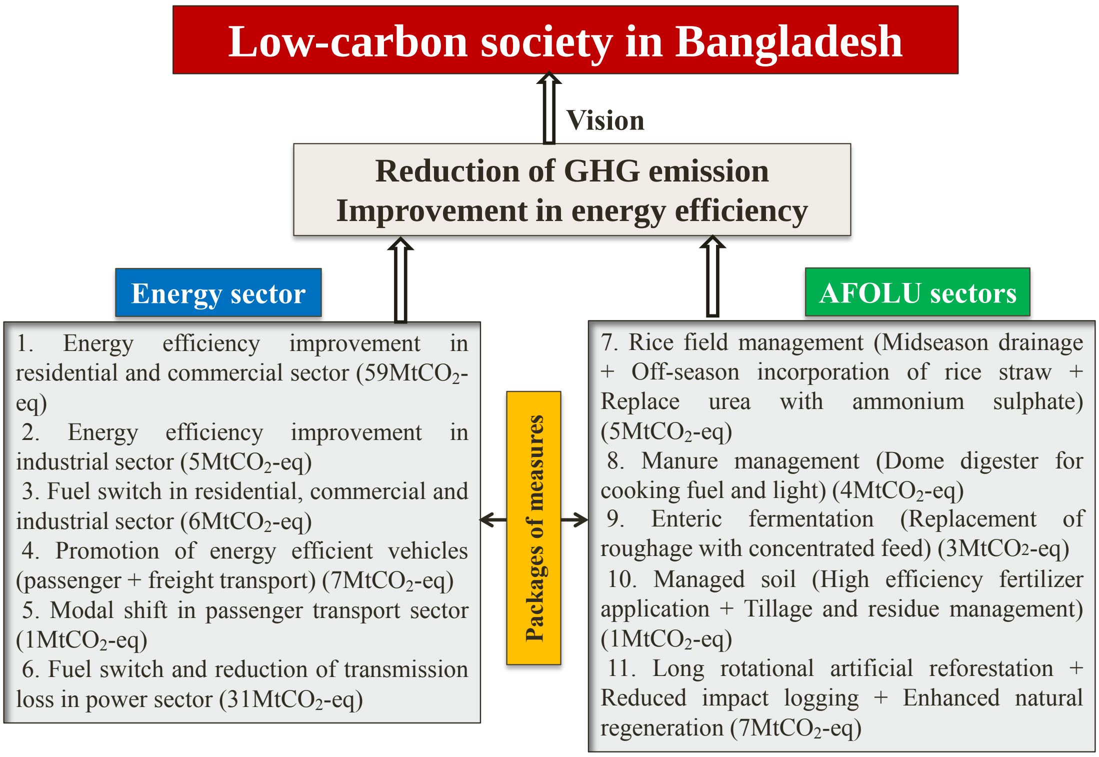


Fig. 7.19 Proposed package of reduction measures for LCS development in Bangladesh

Chapter 8 Conclusions and recommendation for future works

8.1. Conclusions of the study

This chapter aims to summarize the thesis' conclusions and provide recommendations for policy implications. Furthermore, the contributions and limitations of this research also provided and along with their recommendations for further research are proposed. In Bangladesh, LCS is relatively new concept. Currently, there is no official document containing roadmaps towards LCS, except for several government's initiatives that are in line with and supportive to the LCS concept. This thesis presents the results of an academic research assessing scenarios of LCS visions 2025 in Bangladesh with associated mitigation actions to achieve the LCS. Proposed package of reduction measures for energy and AFOLU sectors are the key steps that can influence the energy consumption pattern and GHG emission in future. These measures have been defined with an understanding of the inherent strengths and potential of Bangladesh which can be explored at this time of rapid economic development. A sustainable low-carbon path taken now can guide tomorrow's growth focusing country's long-term development priorities in a more holistic and inclusive manner. It is important to note that promotion of any kind of reduction measure requires concrete strategies and mechanisms before getting the benefit by implementation. Current study will provide the important information on future scenario of GHG emission and reduction, energy demand and supply, sustainable agriculture and forestry and recommended actions to be taken in the modification of those strategies to make the realistic development plan. Moreover, this study results can be set as preliminary step for the policymakers to precede discussion with respect to energy conservation, economic development and overall sustainable development in Bangladesh. Also, encourage the country capable of higher emission reduction to achieve these levels earlier through the use of better technology or other sectoral measures in order to market their emission credits.

The main findings of this study are as follows:

- Industrial production will be increased 3.6 times in 2025.
- Agricultural harvest area and livestock will be increased 1.2 and 1.4 times respectively in 2025.
- GHG emission will be increased to 309.8 $MtCO_2$-eq or 3.5 times larger in 2025BaU than 2005 and reduction measure contributes 41% (127.4 $MtCO_2$-eq) of GHG emission reduction in 2025CM from 2025BaU.
- Residential sector (including electricity) is the highest contributor of about 151 $MtCO_2$-eq or 49% of GHG emission in 2025BaU.
- Energy efficiency improvement in the residential sector's devices contributed 51.7 $MtCO_2$-eq or 41% emission reduction of total in 2025CM, in which lighting (CFL bulb) contributed 28% of total GHG emission reduction.
- Power sector contributed 24% of total GHG emission reduction in CM case through fuel switch and applying low-carbon energy mix.
- Primary energy demand increases to 95Mtoe and 64Mtoe, which are 4.6 times and 3.1 times larger in 2025BaU and 2025CM respectively than the level in 2005.
- Coal usages (mainly in power generation) increases 28% of total primary energy demand in 2025BaU, which will be reduced to 18% in 2025CM case from baseline case.
- Residential sector is the highest energy consumer and consumes 66% of more energy in 2025BaU; consumption will be reduced 33% in 2025CM from 2025BaU level.
- Efficient lighting and cooking in residential sector are the most potential measures resulting in 25% and 13% of energy saving respectively in 2025CM.
- In agricultural sector, this study shows 10.1 $MtCO_2$-eq of emission can be reduced at 0 US$/$tCO_2$-eq in 2025 by no-regret technologies; MD, BM and RRC.

- At 10 US$/t$CO_2$-eq, BM and MD are expected to be the most efficient technologies to reducing about 4.1 MtCO_2-eq and 2.6 MtCO_2-eq (32% and 21% of emission in 2025) respectively in this sector.
- In LULUCF sectors, reduced impact logging (RIL) and enhanced natural regeneration (ENR) are the most cost-effective technologies in Bangladesh.
- At mitigation cost of 500 million US$, 39.6 Mt$CO_2$-eq of mitigation potential can be achieved in total. The LULUCF mitigation technologies have a great potential to recover total emission from LULUCF in 2005 which is more than the total emission from energy sector in 2005 (Energy sector: 31.7 MtCO_2-eq) in Bangladesh.
- Long rotational artificial reforestation (LRR) has more cost effective than SRP/SRR even though they will take a long time (40 years) to make effects. A long-term mitigation target and a long-term viewpoint in technology selection will play a key role in emission mitigation in LULUCF sector of Bangladesh.

8.2. Recommendation for future works

In spite of every effort to pursue the objectives of this research, there are some limitations of the study. It focused on energy sector and AFOLU sector while other aspects such as waste and industrial processes are also one of the sources of CO_2 emission are therefore not within the scope of the study. The scope of the study would be extended to broader area including other sectors that cause GHG emission. In terms of development of modeling, for ExSS model, it should be considered the issue of transportation model especially international transportation problems. For the AFOLU model, it considers only emission part in one certain society. As for further study, it should be developed model for example AFOLU Activities model (AFOLUA) which is top-down model to estimate amounts of human activities in AFOLU sector based on population and socio-economic indicators. The AFOLUA model aims to discuss mitigation potential in AFOLU sectors in different socio-economic scenarios including different GDP and population. Last but not least, in order to attain required actions which introduced in the target year, a roadmap that specified what kind of policy must be done is required in future study. A roadmap is a schedule of actions/countermeasures spread and introduction of the policies.

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Tahsin Jilani

APPENDICES

Appendix 1 Lists of socio-economic indicators used in this study

Code in ExSS	Name		Value		Unit	Source
POP	Population by age and sex		139760000		person	Bangladesh Bureau of Statistics/Planning Division, Ministry of Planning, Gender Statistics of Bangladesh, 2008.
	Male		Urban	Rural		
		0-14	5,816,160	19,871,460		
		15-64	10,849,908	30,385,460		
		65+	623,160	2,460,276		
	Female					
		0-14	5,677,680	19,450,900		
		15-64	11,078,400	30,700,880		
		65+	574,692	2,271,024		
HHD	Number of households		28,522,449		household	Statistical Year Book of Bangladesh, 2009 , Bangladesh Bureau of Statistics
	Number of workers by indystry				person	Statistical Year Book of Bangladesh, 2009 , Bangladesh Bureau of Statistics
	Agriculture and forestry		46,226,855			
	Fishing		1,729,459			
	Mining and quarrying		120,581			
	Manufacturing		10,238,064			
	Electricity, Gas, Water		104,297			
	Construction		2,178,499			
	Whole sale and retail trade		9,774,537			
	Hotel and Restaurant		1,033,188			
	Transport, storage and communication		5,123,882			
	Bank, insurance and Finance		985,761			
	Real estate, rent and business		337,910			
	Public administration		1,410,355			
	Education service		2,605,631			
	Health and social worker		810,802			
	Community, social and private household		5,980,350			
PD	Output by industry				million taka	Converted to IO table 2005 from IO table 2000
	Agriculture and forestry		1,459,345			
	Fishing		404,887			
	Minning and Quarrying		202,902			
	Manufacturing and Commercial goods		3,042,402			
	Construction		656,219			
	Electricity, gas & water		130,725			
	Wholesale and retail trade		701,368			
	Transport services		641,479			
	Real estate & renting business		492,430			
	Education and Health		239,115			
	Government services		167,560			
	Other private services		793,145			

Code in ExSS	Name	Value	Unit	Source
Ptg	Passenger transport generation per person per day	2	:rip/capita/day	calculated by total passenger transport volume and population
Pts	Modal share			calculated by passenger transport volume by type of transport
	Railways	0.001		
	Bus	NI		
	Waterway	0.002		
	Road vehicle	0.022		
	Walk	0.488		
	Bicycle	0.488		
	Aviation	NI		
Ptad	Average trip distance		km/trip	estimated by passenger transport volume, modal share, passenger transport generation per person per day, and population
	Railways	132		
	Bus	NI		
	Waterway	71.5		
	Road vehicle	37.5		
	Walk	2.5		
	Bicycle	2.5		
	Aviation	NI		
PTD	Passenger transport volume	360698	mil p-km	Roads and Railways Division/Ministry of Communications, Transport and Communications, 2010
	Railways	13,440		
	Bus	NI		
	Waterway	14,560		
	Road vehicle	84,000		
	Walk	124,349		
	Bicycle	124,349		
	Aviation	NI		
Ftg	Frieght transport generation per output	0.023	t-output	calculated by total freight transport volume and output of industry
Fts	Modal share			calculated by freight transport volume by type of transport
	Railways	0.16		
	Road vehicle	0.8		
	Waterway	0.04		
	Aviation	NI		
Ftad	Average trip distance		km/trip	estimated by freight transport volume, modal share, freight transport generation per output per day, and population
	Railways	82		
	Road vehicle	158		
	Waterway	115		
	Aviation	NI		
FTD	Frieght transport volume	20	bil-t/km	Roads and Railways Division/Ministry of Communications, Transport and Communications, 2010
	Railways	0.47		
	Road vehicle	17.39		
	Waterway	2.54		
	Aviation	NI		

Appendix 2 Input-output (IO) table of Bangladesh in 2025 (billion taka),

Description	Agriculture and forestry	Fishing	Minning and Quarrying	Manufacturing	Construction	Electricity, gas & water	Wholesale and retail trade	Transport services	Real estate & renting business	Education and Health	Government services	Other private service s	Total intermediate consumption
Agriculture and forestry	846	13	0	3,094	187	0	0	0	0	2	0	130	4,272
Fishing	3	134	0	627	0	0	0	0	0	0	0	22	785
Minning and Quarrying	63	41	43	276	47	27	49	67	103	15	16	90	836
Manufacturing and Commercial goods	434	302	94	1,427	668	82	161	269	195	149	52	369	4,202
Construction	14	0	17	16	12	3	18	71	34	5	6	20	216
Electricity, gas & water	2	16	33	82	84	40	1	19	5	1	1	7	292
Wholesale and retail trade	407	248	153	1,559	0	65	0	0	0	0	0	0	2,431
Transport services	215	0	146	1,211	57	55	68	64	0	0	18	8	1,841
Real estate & renting	7	4	57	144	0	3	86	94	143	21	11	116	683
Education and Health	109	0	0	0	0	0	0	0	0	0	34	20	162
Government services	0	1	10	0	3	3	3	5	10	3	4	4	47
Other private services	136	40	63	529	100	48	93	149	193	93	90	625	2,160
Total Intermediate Input	2,235	798	615	8,967	1,156	325	480	738	682	290	230	1,411	17,928
Labor	590	149	53	1,047	551	53	1,219	799	711	515	493	1,190	7,369
Capital	857	342	103	1,498	791	135	729	529	581	325	189	665	6,743
Indirect Tax	0	0	24	112	20	45	3	0	0	0	0	36	239
Value Added	1,447	491	179	2,656	1,362	232	1,950	1,328	1,292	839	683	1,891	14,351
Total Gross Input	3,682	1,289	794	11,622	2,519	558	2,431	2,066	1,974	1,129	913	3,302	32,279

Appendix 2 Input-output (IO) table of Bangladesh in 2025 (billion taka),

Description	Private consumption	Government consumption	Gross domestic capital formation	Export	Import	Final Demand	Total Gross Output
Agriculture and forestry	660	0	35	81	-1,366	-590	3,682
Fishing	262	0	109	133	0	504	1,289
Minning and Quarrying	461	0	-30	10	-483	-42	794
Manufacturing and Commercial goods	6,839	0	1,138	2,422	-2,978	7,421	11,622
Construction	0	0	2,302	0	0	2,302	2,519
Electricity, gas & water	302	0	0	0	-36	266	558
Wholesale and retail trade	0	0	0	0	0	0	2,431
Transport services	126	0	0	99	0	225	2,066
Real estate & renting business	1,292	0	0	0	0	1,292	1,974
Education and Health	692	348	0	0	-73	967	1,129
Government services	340	440	0	86	0	866	913
Other private services	1,054	0	0	91	-3	1,142	3,302
Total Intermediate Input	12,028	788	3,554	2,922	-4,940	14,351	32,279

Appendix 3 List of countermeasures

Sector	Low-carbon measures and technologies	Specification			Source measure setting (Service type)	
Residential	Air conditioner (highest efficiency)	COP	6.60	*2	Diffusion rate (cooling)	60%
	Oil water heater (high efficiency)	COP	0.83	*1	Diffusion rate (hot water: petrolium)	(6-9)%
	Gas heater (letent heat recovery)	COP	0.83	*1	Diffusion rate (hot water: gas)	(9-40)%
	Heat pump water heater	COP	4.5	*1	Diffusion rate (hot water: electricity)	(5-6)%
	Gas stove (high efficiency)	Thermal efficiency (base year=1)	1.22	*1	Diffusion rate (kitchen:gas)	(10-40)%
	Efficiency improvement of other electric appliances	Electricity consumption (base year=1)	0.48	*1	Electricity consumption (base year=1)	0.48
	Flurorescent light (hf type)	Electricity consumption (base year=1)	1.33	*1	Diffusion rate (Fluroescent)	(38-74)%
	Air conditioner cooling dedicated (highest efficiency)	COP	4.07	*1	Diffusion rate (cooling:electricity)	100%
	Gas heater (high efficiency)	COP	0.87	*1	Diffusion rate (hot water:gas)	60-100)%
	CO_2 refrigerent water heater	COP	3	*1	Diffusion rate (hot water)	25%
	Gas kitchen (high efficiency)	Thermal efficiency (base year=1)	1.15	*1	Diffision rate (Kitchen:gas)	60-100)%
Commercial	Efficiency improvement of other electric devices	Electricity consumption (base year=1)	0.41	*1	Electricity consumption (base year=1)	0.41
	Flurorescent light alternative, timer controlled	Electricity consumption (base year=1)	3.95	*1	Diffusion rate (Fluorescent)	100%
	Behavior changes forenergy saving			*3		
	Cooling	Reduction rate of energy service	20%		Diffusion rate	50%
Industrial	High efficient industrial devices					
	High efficient boiler				Diffusion rate	100%
	High efficient industrial furnace				Diffusion rate	100%
	High efficient motor				Diffusion rate	100%
	Fuel shift				Conversion ratio	(20-80)%
Passenger transport	Modal shift				Conversion ratio	3%
					Conversion ratio	5%
Freight transport	Modal shift				Conversion ratio	10%

*1 Mizuho Information & Research Institute, Inc. (2005): Report on investigation for scenario making and simulation program "Chapter 4 Scenario of measures"

*2 The Energy Conservation Center, Japan (2007): Catalog of energy-saving performance 2007 winter

*3 Shiga Prefecture Sustainable Society Research Team, Japan (2005): Report of the study project to create sustainable society in Shiga Prefecture

Appendix 4 Tables use to split energy demand by energy service type in industrial sector

Appendix 4.1 Iron and Steel industry

Industry		Iron and Steel						
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISIS	ISIS	IPIS	IMIS	IEIS	IOIS	Total
Electricity	INDELC			0.29	0.69		0.02	1.00
Natural Gas	INDNGA	0.07		0.82			0.11	1.00
LPG	INDLPG	0.03		0.95			0.02	1.00
NGL	INDNGL							1.00
Coal	INDCOA			1.00				1.00
Ovencoke	INDCOK							1.00
Coke Oven Gas	INDCOG	0.18		0.82				1.00
Blast Furnace Gas	INDBFG	0.06		0.92			0.02	1.00
Oxygen Steel Furnace Gas	]INDOXY			1.00				1.00
Heavy Fuel Oil	INDHFO	0.18		0.82				1.00
Refined Petroleum Products	INDOIL	0.06		0.84	0.08		0.02	1.00
Ethane	INDETH							1.00
Naphta	INDNAP							1.00
Petroleum Coke	INDPTC							1.00
Biofuels	INDBIO	1.00						1.00
Geothermal	INDGEO	1.00						1.00
Heat	INDHET			1.00				1.00

Appendix 4.2 Non Ferrous metals Industry

Industry		Non Ferrous metals						
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISNF	ISNF	IPNF	IMNF	IENF	IONF	Total
Electricity	INDELC			0.47	0.35	0.15	0.03	1.00
Natural Gas	INDNGA	0.11		0.86			0.03	1.00
LPG	INDLPG			1.00			0.00	1.00
NGL	INDNGL						1.00	1.00
Coal	INDCOA	0.38		0.62				1.00
Ovencoke	INDCOK			1.00				1.00
Coke Oven Gas	INDCOG			1.00				1.00
Blast Furnace Gas	INDBFG			1.00				1.00
Oxygen Steel Furnace Gas	]INDOXY			1.00				1.00
Heavy Fuel Oil	INDHFO	0.25		0.74	0.01			1.00
Refined Petroleum Products	INDOIL	0.25		0.59	0.05		0.11	1.00
Ethane	INDETH							1.00
Naphta	INDNAP							1.00
Petroleum Coke	INDPTC						1.00	1.00
Biofuels	INDBIO	1.00						1.00
Geothermal	INDGEO	1.00						1.00
Heat	INDHET			0.55			0.45	1.00

Appendix 4.3 Chemical Industry

Industry		Chemicals							
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Feed-stocks	Others	Total
		ISCH	ISCH	IPCH	IMCH	IECH	IFCH	IOCH	
Electricity	INDELC			0.05	0.81	0.10		0.04	1.00
Natural Gas	INDNGA	0.08		0.13	0.00		0.78	0.00	1.00
LPG	INDLPG						1.00		1.00
NGL	INDNGL						1.00		1.00
Coal	INDCOA	1.00							1.00
Ovencoke	INDCOK							1.00	1.00
Coke Oven Gas	INDCOG			1.00					1.00
Blast Furnace Gas	INDBFG			1.00					1.00
Oxygen Steel Furnace Gas	]INDOXY			1.00					1.00
Heavy Fuel Oil	INDHFO	0.69		0.05	0.00		0.26		1.00
Refined Petroleum Products	INDOIL	0.50		0.30	0.03		0.17		1.00
Ethane	INDETH						1.00		1.00
Naphta	INDNAP						1.00		1.00
Petroleum Coke	INDPTC							1.00	1.00
Biofuels	INDBIO	1.00							1.00
Geothermal	INDGEO	1.00							1.00
Heat	INDHET	0.00		0.73	0.09			0.18	1.00

Appendix 4.4 Paper and Pulp Industry

Industry		Pulp and paper						
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISLP	ISLP	IPLP	IMLP	IELP	IOLP	Total
Electricity	INDELC			0.00	0.95	0.00	0.05	1.00
Natural Gas	INDNGA	0.80		0.19			0.01	1.00
LPG	INDLPG	0.23		0.69			0.07	1.00
NGL	INDNGL							1.00
Coal	INDCOA	0.89		0.01			0.10	1.00
Ovencoke	INDCOK							1.00
Coke Oven Gas	INDCOG							
Blast Furnace Gas	INDBFG	1.00						1.00
Oxygen Steel Furnace Gas	]INDOXY	1.00						1.00
Heavy Fuel Oil	INDHFO	0.90		0.10	0.00		0.00	1.00
Refined Petroleum Products	INDOIL	0.29		0.15			0.56	1.00
Ethane	INDETH							1.00
Naphta	INDNAP							1.00
Petroleum Coke	INDPTC						1.00	1.00
Biofuels	INDBIO	0.40		0.60				1.00
Geothermal	INDGEO	1.00						1.00

Appendix 4.5 Non-metal minerals Industry

Industry		Non metal minerals						
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISNM	ISNM	IPNM	IMNM	IENM	IONM	Total
Electricity	INDELC			0.06	0.88	0.00	0.06	1.00
Natural Gas	INDNGA	0.13		0.82			0.05	1.00
LPG	INDLPG	0.04		0.88			0.08	1.00
NGL	INDNGL						1.00	1.00
Coal	INDCOA			1.00				1.00
Ovencoke	INDCOK							1.00
Coke Oven Gas	INDCOG			1.00				1.00
Blast Furnace Gas	INDBFG			1.00				1.00
Oxygen Steel Furnace Gas	]INDOXY			1.00				1.00
Heavy Fuel Oil	INDHFO	0.13		0.84	0.02		0.00	1.00
Refined Petroleum Products	INDOIL	0.35		0.47	0.07		0.11	1.00
Ethane	INDETH							1.00
Naphta	INDNAP							1.00
Petroleum Coke	INDPTC						1.00	1.00
Biofuels	INDBIO	1.00						1.00
Geothermal	INDGEO	1.00						1.00
Heat	INDHET	1.00						1.00

Appendix 4.6 Other industries

Industry		Other industries						
		Boilers	Boilers	Process Heat	Machine Drive	Electro-chemical	Others	
		ISOI	ISOI	IPOI	IMOI	IEOI	IOOI	Total
Electricity	INDELC			0.09	0.78	0.03	0.10	1.00
Natural Gas	INDNGA	0.49		0.38	0.01		0.12	1.00
LPG	INDLPG	0.06		0.65	0.01		0.28	1.00
NGL	INDNGL							1.00
Coal	INDCOA	0.41		0.49			0.10	1.00
Ovencoke	INDCOK						1.00	1.00
Coke Oven Gas	INDCOG							
Blast Furnace Gas	INDBFG	1.00						1.00
Oxygen Steel Furnace Gas	]INDOXY	1.00						1.00
Heavy Fuel Oil	INDHFO	0.70		0.29	0.00		0.01	1.00
Refined Petroleum Products	INDOIL	0.47		0.13	0.08		0.32	1.00
Ethane	INDETH							1.00
Naphta	INDNAP							1.00
Petroleum Coke	INDPTC	1.00						1.00
Biofuels	INDBIO	1.00						1.00
Geothermal	INDGEO	1.00						1.00
Heat	INDHET			0.63	0.01		0.35	1.00

Appendix 5 Table used to split energy demand by energy service type in residential

Residential		Space heating	Space cooling	Hot water heating	Refrigerators and freezers	Cloth dryer	Cooking	Cloth washers	Dish washers	Other energy uses	Miscellaneous electric energy	Lighting	
		RH1	RC1	RHW	RRF	RCD	RK1	RCW	RDW	ROT	REA	RL1	Total
Natural gas	RESNGA	10%		35%			40%			15%			100%
Diesel	RESDST	20%		50%						30%			100%
Heavy fuel oil	RESHFO	100%											100%
Kerosene	RESKER	15%		30%			40%					15%	100%
Coal	RESCOA	50%		40%			10%						100%
LPG	RESLPG	25%		40%			35%						100%
Biofuels	RESBIO	20%		30%			50%						100%
Electiricity	RESELC	2%	8%	8%	10%	1%	5%	3%	1%		20%	42%	100%
Heat	RESHET	100%											100%
Geothermal	RESGEO	100%											100%
Solar	RESSOL			100%									100%

Appendix 6 Table used to split energy demand by energy service type in commercial

Commeciral		Space heating	Space cooling	Hot water heating	Lighting	Cooking	Refrigerators and freezers	Electric Equipment	Other Energy Use	Other energy uses
		CH1	CC1	CHW	CLA	CCK	CRF	COE	COT	Total
Natural gas	COMNGA	15%		40%		40%			5%	100%
Diesel	COMDST	50%		50%						100%
Heavy fuel oil	COMHFO	70%		30%						100%
Kerosene	COMKER	50%		40%		10%				100%
Coal	COMCOA	60%		30%		10%				100%
LPG	COMLPG	60%		35%		5%				100%
Biofuels	COMBIO	30%		30%		40%				100%
Electiricity	COMELC	3%	13%	6%	35%	1%	20%	22%		100%
Heat	COMHET	100%								100%
Geothermal	COMGEO	100%								100%
Solar	COMSOL			100%						100%

Appendix 7 Tables used to split energy demand by energy service type in transport sector

Appendix 7.1 Freight transport sector

Transportation		SHIP Total	Freight ship	Passenger ship	AIR Total	Freight air	Passenger air
Coal	TRACOA	0	0	0	0	0	0
Methanol	TRAMET	0	0	0	0	0	0
Ethanol	TRAETH	0	0	0	0	0	0
Natural gas	TRANGA	0	0	0	0	0	0
LPG	TRALPG	0	0	0	0	0	0
Gasoline	TRAGSL	0	0	0	0	0	0
Aviation Gasoline	TRAAVG	0	0	0	0	0	0
Jet Kerosene	TRAJTK	0	0	0	265	0	265
Diesel	TRADST	0	0	0	0	0	0
Heavy Fuel Oil	TRAHFO	0	0	0	0	0	0
Electiricity	TRAELC	0	0	0	0	0	0

Appendix 7.2 Passenger transport sector

Transportation		ROAD										RAIL		
		Light Vehicle					Other Vehicle					Total		
			Autos	Light trucks	Three wheels	Two wheels		Buses	Heavy trucks	Medium trucks	Commercial trucks		Freight rail	Passenger rail
			TRT	TRL	TRE	TRW		TRB	TRH	TRM	TRC		TTF	TTP
Coal	TRACOA											100%	80%	20%
Methanol	TRAMET	90%	80%	20%			10%	50%		50%				
Ethanol	TRAETH	90%	80%	20%			10%	50%		50%				
Natural gas	TRANGA	90%	80%	20%			10%	70%			30%			
LPG	TRALPG	70%	67%	33%			30%	70%			30%			
Gasoline	TRAGSL	70%	57%	40%	1%	3%	30%	20%	10%	35%	35%			
Aviation Gasoline	TRAAVG													
Jet Kerosene	TRAJTK													
Diesel	TRADST	5%	35%	65%			95%	20%	50%	25%	5%	100%	80%	20%
Heavy Fuel Oil	TRAHFO											100%	90%	10%
Electiricity	TRAELC	100%	90%	10%			0%					100%	5%	95%

Appendix 8 Formulation of ExSS model

Household

Number of household

$$HHD_{hht} = \sum_{age} \underline{Pop}_{age,hht} \Big/ \underline{Pphhd}_{hht}$$

HHD_{hht} : Number of household by household type *hht* [number]

$\underline{Pop}_{age,hht}$: Population by age cohort *age* by household type *hht* [number]

$\underline{Pphhd}_{hht}$: Person per household by household type *hht* [number]

hht : Household type ($\in eds$)

age : Age cohort

Economy

Inverse matrix of Leontief

$$\sum_{j}(\underline{Imat}_{i,j} - (1 - \underline{IMR}_{i}) \times \underline{Amat}_{i,j} \times Ainv_{j,k}) = \underline{Imat}_{i,k}$$

$\underline{Imat}_{i,j}$: Unit matrix

$\underline{Mr}_{i}$: Import ratio of industry *i* (= import / regional demand) [ratio ≦ 1]

$\underline{Amat}_{i,j}$: Input coefficient matrix (input coefficient to industry *i* from industry *j*) [share, $\sum_{j} \underline{Amat}_{i,j} = 1$]

$Ainv_{i,j}$: Inverse matrix of Leontief (Here, $(I-(I-\overline{M})A)^{-1}$ type is applied.) [number]

i,*j*,*k* : industry (=*pds*)

Domestic final demand

$$FD_{pds} = \sum_{dfds}(\underline{FD\_ttl}_{dfds} \times \underline{FD\_cvm}_{pds,dfds})$$

FD_{pds} : Domestic final demand to industry *pds* [monetary]

$\underline{FD\_ttl}_{dfds}$: Total final demand of domestic final demand sector *dfds* [monetary]

$\underline{FD\_cvm}_{pds,dfds}$: Converter matrix of final demand (share of industry *pds* in final demand sector *dfds*) [share, $\sum_j \underline{FD\_cvm}_{i,j} = 1$]

dfds : Domestic final demand sector ($\in fds$)

fds : Final demand sector (including *dfds*, export and import)

Industrial output

$$EX_j = \underline{FD\_ttl}_{ex} \times \underline{FD\_cvm}_{j,ex}$$

$$PD_i = \sum_j (Ainv_{i,j} \times (((1 - \underline{Mr}_j) \times FD_j) + EX_j))$$

PD_i : Gross output of industry *i* [monetary]

$\underline{EX}_j$: Export of insutry *j* [monetary]

$\underline{FD\_ttl}_{ex}$: Total export [monetary]

$\underline{FD\_cvm}_{ex,j}$: Share of industry *j* in export [share, $\sum_j \underline{FD\_cvm}_{ex,j} = 1$]

ex: export ($\in fds$)

Intermediate input

$$SAM_{sams,pds} = PD_{pds} \times \underline{Amat}_{sams,pds}$$

$\underline{SAM}_{sams,pds}$: Intermediate input from sector *sams* to industry *pds*

sams :Elements of IO table (industry *pds*, value added sector *vas*)

Import

$$IM_{pds} = (FD_{pds} + \sum_j SAM_{pds,j}) \times \underline{Mr}_{pds}$$

IM_{pds} : Import of goods or services produced by industry *pds* [monetary]

Commercial buildings

Floor area of commercial buildings

$$CFA_{svs} = PD_{svs} \times \underline{Fag}_{svs}$$

CFA_{svs} : Floor area of commercial buildings of tertiary industry svs [km^2]

$\underline{FAG}_{svs}$: Floor are per output of tertiary industry svs [km^2/monetary]

svs : Tertiary industry ($\in pds$)

Transport

Passenger transport demand

$$PTD_{ptm} = \sum_{td}\sum_{age}\sum_{hht} \underline{Pop}_{age,hht} \times \underline{Ptg}_{age,td} \times \underline{Pts}_{td,ptm} \times \underline{Ptad}_{td,ptm} \times 365 \times (1/10^6)$$

PTD_{ptm}: Pssenger transport demand [million passenger-km]

$\underline{Pop}_{age,hht}$: Population by age cohort and household type [number]

$\underline{Ptg}_{age,td}$: Trip per parson per day by age cohort and transport destination [passenger-trip/population/day]

$\underline{Pts}_{td,ptm}$: Modal share of passenger transport [share, trip/trip, $\sum_{ptm} Pts_{td,ptm} = 1$]

$\underline{Ptad}_{td,ptm}$: Average trip distance of passenger transport [km]

ptm : passenger transport mode ($\in eds$,$\in esc$)

td : transport destination

Freight transport demand

$$FTD_{ftm} = \sum_{pss}\sum_{td} PD_{pss} \times \underline{Ftg}_{pss,td} \times \underline{Fts}_{td,ftm} \times \underline{Ftad}_{td,ftm} \times (1/10^6)$$

FTD_{ftm}: Freight transport demand [mill. ton-km]

PD_{pss}: Output of primary and secondary industry [monetary]

$\underline{Ftg}_{pss,td}$: Freight generation per industrial output [ton/ monetary]

$\underline{Fts}_{td,ftm}$: Modal share of freight transport [share, ton/ton, $\sum_{ftm} Fts_{td,ftm} = 1$]

$\underline{Ftad}_{td,ftm}$: Average distance of freight transport [km].

pss: primary and secondary industry ($\in pds$)

ftm : freight transport mode ($\in eds, \in esc$)

Energy demand

Energy service demand

$$ESDF_{eds,esv} = \begin{cases} HHD_{hht} & (for \quad \text{hht}) \\ FA_{svs} & (for \quad \text{svs}) \\ PD_{pss} & (for \quad \text{pss}) \\ \sum_{td}\sum_{age}\sum_{hht} \underline{Pop}_{age,hht} \times \underline{Ptg}_{age,td} \times \underline{Pts}_{td,ptm} \times 365 \times (1/10^6) & (for \quad ptm) \\ \sum_{pss}\sum_{td} PD_{pss} \times \underline{Ftg}_{pss,td} \times \underline{Fts}_{td,ftm} \times (1/10^6) & (for \quad ftm) \end{cases}$$

$$ESVD_{eds,esv} = ESDF_{eds,esv} \times \underline{Esvg}_{eds,esv}$$

$ESDF_{eds,esc}$: Driving force of energy demand sector *eds*, energy service *esc* [*unit depends on the sector*]

$ESVD_{eds,esc}$: Energy service demand of energy demand sector *eds*, energy service *esc* [*unit depends on the sector and service*]

$\underline{Esvg}_{eds,esc}$: Energy service demand per driving force of energy demand sector *eds*, energy service *esc* [*unit depends on the sector and service*]

eds : Energy demand sector

esv : Energy service

Primary energy demand

$$PED_e = \sum_{eds}\sum_{esv} ED_{eds,esv,nele} + \sum_{eds} DPG\_ed_{eds,nele} + CPG\_ed_{nele}$$

PED_e : Primary energy demand of fuel *e*

Final energy demand

$$TCef_{eds,esv,e,device} = \underline{TCsv}_{eds,esv,e,device} / \underline{TCed}_{eds,esv,e,device}$$

$$ES_{eds,esv,e} = \sum_{tc} \underline{TCsh}_{eds,esv,e,device}$$

$$EF_{eds,esv,e} = \frac{\sum_{tc}\left(TCef_{eds,esv,e,device} \times \underline{TCsh}_{eds,esv,e,device}\right)}{ES_{eds,esv,e}}$$

$$ED_{eds,esv,e} = ESVD_{eds,esv} \times ES_{eds,esv,e} \times EF_{eds,esv,e}$$

$TCef_{eds,esv,e,device}$: Energy efficiency of energy demand sector ***eds*, energy service *esv*, fuel *e*, energy endues device *device***

$\underline{TCsh}_{eds,esv,e,device}$: Device share energy demand sector ***eds*, energy service *esv*, fuel *e*, energy endues device *device* (**$\sum_{e}\sum_{tc} TCSH_{eds,esc,e,device} = 1$**)**

$\underline{TCsv}_{eds,esv,e,device}$: Energy service supplied by **energy endues device *device*** of energy demand sector ***eds*, energy service *esv*, fuel *e*. (service supplied by** $\underline{TCed}_{eds,esv,e, device}$*)*[*unit depends on the service*]

$\underline{TCed}_{eds,esv,e,device}$: Energy required for **energy endues device *device*** of energy demand sector ***eds*, energy service *esv*, fuel *e*. (energy required by** $\underline{TCsv}_{eds,esv,e, device}$*)* [ktoe/service]

$ED_{eds,esv,e}$: Final energy demand of energy demand sector ***eds*, energy service *esv*, fuel *e*** [ktoe]

$\underline{ES}_{eds,esv,e}$: Fuel share of energy demand sector ***eds*, energy service *esv*, fuel *e***

$\underline{EF}_{eds,esv,e}$: Energy efficiency of energy demand sector ***eds*, energy service *esv*, fuel *e* [**share]

device: Energy enduse devic

Energy supply

Central power generation

$$ELD\_cps_{eds} = \sum_{esv} ED_{eds,esv,ele} - \sum_{e} \underline{DPG}_{eds,e}$$

$$CPG_e = \sum_{eds} ELD\_cps_{eds} \times \underline{CPGsh}_e$$

Where,

ELD_cps_{eds}: Electricity demand to central power generation from energy demand sector *eds*

$ED_{eds, esv, ele}$: Final electricity demand of energy demand sector *eds,* energy service *esv*

$\underline{DPG}_{eds}$: dispersed power generation in energy demand sector *eds*.

CPG_e: Power supply by central power generation by fuel *e*

$\underline{CPGsh}_e$: Share of power supply in central power generation by fuel *e* [share, ktoe/ktoe, $\sum_e \underline{CPGsh}_e = 1$]

ele: Electricty ($\in e$)

Primary energy demand of power generation

$$DPG\_ed_{eds,e} = \left[\frac{\underline{DPG}_{eds,e}}{\underline{DPGef}_{eds,es} \times (1 - \underline{DPGown}_{eds,e})} \right]$$

$$CPG\_ed_e = \frac{CPG_e}{\underline{CPGef}_e \times (1 - \underline{CPGown}_e) \times (1 - \underline{CPGtl}_e)}$$

$DPG\_ed_{eds,e}$: Energy demand of fuel *e*, dispersed power generation at energy demand sector *eds* [ktoe]

$\underline{DPGef}_{eds,e}$: Energy efficiency of fuel *e*, dispersed power generation at energy demand sector *eds* **[generation/ input fuel, ktoe/ktoe]**

$\underline{DPGown}_{,e}$: Own use ratio of fuel *e*, dispersed power generation at energy demand sector *eds* [ratio, ktoe/ktoe]

CPG_ed_e: Energy demand of fuel *e*, central power generation [ktoe]

$\underline{CPGef_e}$: Energy efficiency of fuel *e*, central power generation **[generation/fuel input, ktoe/ktoe]**

$\underline{CPGown_e}$: Own use ratio of fuel *e*, central power generation [own use/generation, ktoe/ktoe]

$\underline{CPGgl_e}$: Transmission loss rate of fuel *e*, central power generation [rate, ktoe/ktoe]

CO_2 emissions

CO_2 emission factor (power generation)

$$DPG\_Co2ef_{eds} = \sum_e (DPGed_{eds,e} \times \underline{Co2ef}_e) / \sum_e \underline{DPG}_{eds,e}$$

$$Co2ef_{ele} = \sum_e (CPGed_e \times \underline{Co2ef}_e) / \sum_e CPG_e$$

$$Ttl\_Co2ef_{eds} = \left(\frac{Eld\_cps_{eds}}{\sum_{esv} ED_{eds,esv,ele}} \right) \times Co2ef_{ele} + \left(1 - \frac{Eld\_cps_{eds}}{\sum_{esv} ED_{eds,esv,ele}} \right) \times DPG\_Co2ef_{eds}$$

DPG_Co2ef_{eds}: CO_2 emission factor of dispersed power generation in energy demand sector *eds* [tC/toe]

$Co2ef_{eds}$: CO_2 emission factor of central power generation [tC/toe]

$\underline{Co2ef_e}$: CO_2 emission factor of fuel *e* [tC/toe]

Ttl_Co2ef_{eds}: CO_2 emission factor of electricity demanded by energy demand sector *eds* [tC/toe]

CO_2 emissions

$$CO2_{eds} = \sum_{esv} \left(\sum_{nele} ED_{eds,esv,nele} \times Co2ef_{nele} + \sum_{esv} ED_{eds,esv,ele} \times Ttl\_Co2ef_{eds} \right)$$

CO_{2eds} : CO_2 emissions of energy demand sector *eds* [ktC]

$ED_{eds,esv,nele}$: Energy demand (except of electricity) of energy demand sector *eds,* energy service *esv* [ktoe]

$nele$: Fuel except of electricity ($\in e$)